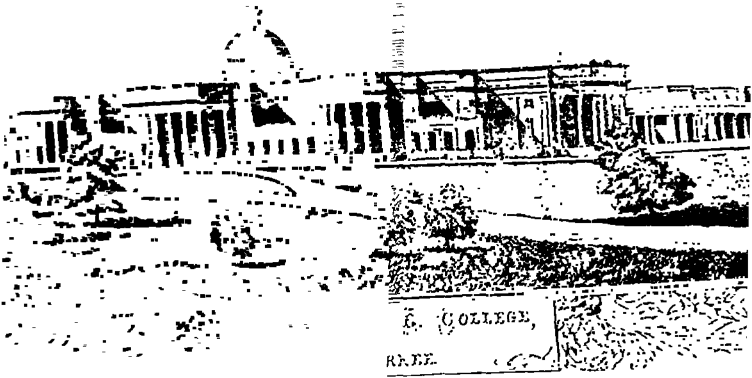

COLLEGE,

THE ROORKEE TREATISE ON CIVIL ENGINEERING IN INDIA.

COMPILED BY

LIEUT.-COL. J. G. MEDLEY, R.E.,

ASSOC. INST. C.E.; PRINCIPAL, THOMASON CIVIL ENGINEERING COLLEGE, ROORKEE.

VOL. I.

THIRD EDITION ENLARGED AND IMPROVED.

EDITED BY

MAJOR A. M. LANG, R.E.,

PRINCIPAL, THOMASON CIVIL ENGINEERING COLLEGE, ROORKEE.

ROORKEE:

PRINTED AND PUBLISHED AT THE THOMASON COLLEGE PRESS.

CALCUTTA: THACKER, SPINK & CO. BOMBAY: THACKER, VINING & CO.

MADRAS: GANTZ, BROTHERS. LONDON: E. & F. N. SPON & CO.

1873.

PREFACE

TO THE

THIRD EDITION OF VOL. I.

The success of Colonel Medley's compilation on the subject of Civil Engineering in India has been attested by the rapid sale of two Editions of this Work. Colonel Medley had proposed to undertake the labor of editing a Third Edition during his furlough in England, but this plan was negatived owing to the decision of the Government that the duty of editing and publishing the "Roorkee Treatise of Civil Engineering" (as a text-book for the Engineering Colleges of India) should remain as heretofore in the hands of the College Staff at Roorkee. Thus, in the absence of the original able Compiler, the duty of editing the Third Edition has devolved upon me.

This Third Edition contains some alterations and many additions, to suit it to the progress of Civil Engineering in this country, and to render it a more complete text-book to the Student, and work of reference to the Engineer in India: the "Professional Papers of Indian Engineering" having been laid under contribution to supply descriptions of new processes introduced during the last few years.

The 'order' of the Sections have been altered from that adopted in the First Editions: in this Edition the more difficult modes of

construction have been made to follow those of a simpler nature. The Section on "Strength of Materials" has been entirely re-written (by Capt. Allan Cunningham, R.E., Mathematical Professor in this College), and has been placed at the end of the Volume; Mathematical investigations in relation to Carpentry and Masonry having been for the most part eliminated from the Sections devoted to those subjects, and collected in this final Section, in which their strictly Scientific and Mathematical (as opposed to their purely experimental and practical) aspect has been considered.

The Section on "Building Materials" has been carefully revised, and enlarged by the addition of supplementary matter, illustrative of improvements in manufacture during late years, and the most recent Indian practice. Among the additions made in this Edition may be noted Manufacture of Artificial Stone—Mode of Blasting in the Mont Cenis Tunnel—Brick-making by Machinery—Hoffmann's Brick-kilns—New list of Indian Timber Trees, with data relative to the strength and elasticity of their wood—and Improvements in Iron and Steel Manufacture.

The Chapter on "Limes and Cements" has been enlarged by additional information in regard to hydraulic cements and concretes; materials which have of late years received increased attention from Engineers and others, and are employed much more extensively than formerly in building operations. The writings of Mr. Henry Reid, C.E., have been consulted for the most recent information on this most important subject; and extracts from the recommendations of Colonel H. A. Brownlow, R.E., and Mr. P. Dejoux, in regard to cement manufacture in India, have been embodied in this work. Reference has been made to experiments in concrete building in India, a mode of construction which promises to be much more ex-

tensively adopted in parts of the country where building stone is not obtainable, while materials for concrete are abundant.

More precise and detailed instructions in regard to Lime and Mortar Analysis have been furnished for this work by Dr. Murray Thomson. The necessity for more intimate knowledge of the composition of building materials, especially of limes, in every part of India, has been demonstrated by recent building failures (due in some cases to inferior materials); and an increased impetus has been given to the more careful study of the local supply of building materials in their immediate neighbourhood by Engineers in charge of important works. Although thorough analysis cannot be conducted without appliances which are not available to many Engineers, yet it is of advantage to know the more simple and approximate methods, and to realize what is required for a more complete analysis. Before long, doubtless, the Government will arrange that more of its Engineers shall be specially instructed in Chemical Analysis, and that at certain local centres such qualified officers shall be located and furnished with the necessary appliances to enable all materials used in building operations in their neighbourhood to be carefully analyzed. There seems to be no reason why, if sufficient technical knowledge could be brought systematically to bear on the subject, concretes and cements should not be manufactured in India of equal quality to those used in Europe, and cheaper in cost: as exemplified by the Experiments on "Margohi Cement," described in the first Appendix of this Volume.

The Section on "Earthwork," as descriptive of the simplest Engineering operations, succeeds that on "Materials;" and contains scarcely any alterations from the former Editions.

In the "Carpentry" Section, the Chapter on Joints and Scarfs

PREFACE TO SECOND EDITION.

THE First Edition of Volume I. has been exhausted rather sooner than I had anticipated, and I have, in consequence, been more hurried in the preparation of a Second Edition than I could have wished. It will, however, I think, be found an improvement on its predecessor.

In the Section on BUILDING MATERIALS, a paragraph has been added on the Manufacture of Artificial Stone; and an additional Chapter has been given on Colored Bricks and Tiles. The process of making the Hollow Hexagonal Tiles, as used in Sindh, and the Drainage Tiles as at Allygurh, has also been described. Paragraphs on the detailed Analysis of Limestone, and on the Manufacture of Hydraulic Lime at Kurrachee, will be found. The Descriptive Catalogue of Indian Timbers has been revised, and many new ones added, chiefly by the aid of Dr. Balfour's valuable work on the Timber Trees of India. Most of this extra matter has been taken from Vols. IV. and V. of the "Professional Papers on Indian Engineering."

In the Section on MASONRY, additional information has been given on the construction of Domes and Oblique and Gothic Arches, and on the Sand-Pump, now used so largely in sinking Foundations.

In the CARPENTRY Section, a Chapter has been given on Floors, Staircases and Partitions. Several additional examples of Roofs will also be found; and the information on the subject of Joints and Scarfs has been rendered much more complete. This valuable additional matter has been extracted from Mr. Newland's excellent work—"The Carpenter and Joiners' Assistant."

To the Section on EARTHWORK has been added an abridgement of O'Callaghan's Tables, which, in a more extended form, were published at this Press some time ago.

In the APPENDIX have been given two or three Notes which came too late to be inserted in the body of the text—some valuable extracts and tables from Molesworth's well known Pocket-book, and a Technical Vocabulary.

The above additions comprise 93 extra pages, while several Plates have also been added. It has been found necessary, therefore, to raise the price, from 5 to 6 Rs.; but it is hoped the additional matter will be thought to compensate for this.

A Second Edition of Vol. II. (of which a much larger number of copies was originally printed than of Vol. I.) will be put in hand at once, and will, I hope, be ready by the time the First Edition is exhausted.

The system upon which this compilation has been made, is—First, to lay down general rules and principles in as systematic a form as the subject admits of. Secondly, to illustrate the application of those rules to practice by reference to examples of Indian Engineering works. To take the Art of Civil Engineering out of the region of empiricism, and bring it to within the confines of

science, ought to be the aim of every Engineer, but the principles on which it rests ought to be derived from the results of actual practice, and not be mere *à priori* theories.

The Mathematical investigations introduced have been made as simple as possible (such as involve the Calculus, *for instance*, having been omitted), but they pre-suppose that the Student has a fair acquaintance with Mathematics, including Statics and Hydraulics, without which, indeed, he must simply work by "rule of thumb."

Although this work professes to be little more than a careful collation of the results and labors of others, it is right to add that the compilation has been tested by the experience gained in eleven years' practice in the construction of Roads, Buildings, Bridges, and Irrigation Works, besides several years devoted to the theory and literature of the profession.

J. G. M.

ROORKEE,
1st *February*, 1869.

PREFACE TO VOL. I.

The large demand for the little Manuals of Civil Engineering, compiled from time to time at the College, chiefly for the use of the Students, has led me to plan a comprehensive Treatise on the whole subject, principally with reference to Indian practice. I have taken the College Manuals as my text, revising them all carefully and adding such supplementary matter as I have been able to collect, illustrative of work actually executed in India. This Treatise is therefore, in no sense a new work, but only a coherent whole, compiled from a number of detached parts; and a small edition only has been printed, that it may be issued with emendations and additions at no distant interval of time.

In the present Volume, Section I., Building Materials, contains the substance of the Manual with that title, with a good deal of additional matter under the headings Stone and Timber, the Chapter on Lime, &c., being abbreviated from the last edition of the Manual of that name.

Section II. comprises the whole of No. II. Manual, with an additional Chapter on Deflection.

Section III. has been compiled from No. VI. Manual, and from Mahan and other good authorities; with some examples selected from the Professional Papers on Indian Engineering.

Section IV. has been compiled from No. XI. Manual, with a few additions.

Section V. is an almost verbatim reprint of No. IV. Manual on Earthwork.

When the Manuals were originally drawn up it was thought needless to encumber their pages with references to the numerous authorities consulted in their preparation, and I have followed the same course with the present work, which professes, like them, to be merely a compilation; but Mahan's and Rankine's Treatises on Civil Engineering, and Tredgold's and Nicholson's Treatises on Carpentry, must be specially mentioned as having been largely extracted from.

Vol. II. on Special Constructions, comprising Section VI., *Buildings;* Section VII., *Bridges;* Section VIII., *Roads;* Section IX., *Railways;* Section X., *Irrigation Works;* will be issued, I hope by the end of this year; and having myself drawn up four out of the five Manuals from which that volume will be chiefly compiled I shall have a claim to a larger share in its preparation than in that of the present one.

I have only to add that at the suggestion of a correspondent, interleaved copies of this volume are available; and if they could be returned to Roorkee, say two years hence, with addenda and alterations, an improved edition might then be prepared.

J. G. M.

CONTENTS.

SECTION I.—BUILDING MATERIALS.

CHAPTER I.—STONE.

CHAPTER II.—BRICKS.

CHAPTER III.—TILES.

CHAPTER IV.—LIMES, CEMENTS, MORTARS, CONCRETES AND PLASTERS.

CHAPTER X.—CUTTINGS.

CHAPTER XI.—EMBANKING AND PUDDLING.

SECTION III.—CARPENTRY.

CHAPTER XII.—JOINTS, SCARFS, TRUSSED AND BUILT BEAMS.

CHAPTER XIII.—ROOFS.

SECTION V.—STRENGTH OF MATERIALS.

CHAPTER XXI.—PRELIMINARY.

CHAPTER XXII.—TENSION.

CHAPTER XXIII.—COMPRESSION.

PAGE.

ADDENDUM TO CHAPTERS XXII. AND XXIII.

CHAPTER XXIV.—STIFFNESS, ELASTICITY, SET.

CHAPTER XXV.—STRESSES IN ROOF TRUSSES.

SECTION I.—BUILDING MATERIALS.

The materials in general use for building will be separately described under the following heads:—Stone, Bricks, Tiles, Lime, Cements and Plasters, Wood, Metals, Paints and Varnishes.

CHAPTER I.

STONE.

1. The use of Stone as a building material is limited by local circumstances. The widely extended plains which cover so large an area in this country, and more particularly in the Upper Provinces, for the most part furnish no materials adapted for this purpose; and, as in other parts of the world similarly situated in this respect, the want is supplied by the use of an artificial substitute. The description of limestone, known by the name of *kunkur*, to be met with pretty generally over a great part of Hindoostan, beneath the surface earth at varying depths, also in the beds and banks of rivers, and commonly existing in the form of rough irregular nodules of small size, is in some places found also in large compact masses, and has been successfully employed as a building stone. But no places where it is só employed, and where masonry works of any extent are to be constructed, are thereby rendered altogether independent of the artificial material; the successful manufacture of which is a matter of the first importance in connection with all works of Architecture and Engineering.

There are, however, parts of India where rubble stone is cheaper than brick, as for instance in Rajpootana, where the easily quarried and slab-like mica slate quite supersedes the use of bricks, and others, as at Saugor, in Central India, where a black soil* prevails, in which beds of clay fit for

* This black soil is generally supposed, though not universally allowed, to be decomposed basalt. The following section of a shaft in the black soil near Saugor is given by Dr. Spry, in the 2nd Vol. of the Journal of the Asiatic Society, page 641:—

Surface soil black, 3 feet; soft basalt, 2½ feet; hard basalt, 7 feet; soft basalt, 1½ feet; wacke, with nodules of limestone, 3 feet; travertine with imbedded shells, 1½ feet; coarse silicious grit, 2 feet; basalt——

brick-making are infrequent; whilst for architectural purposes, the white marble of Jeypore, and the freestones of Agra, Delhi, Mirzapore and Chunar, are well known.

2. It is almost superfluous to say that the choice of stone for a building intended to endure for ages is of the very highest importance. Great numbers of beautiful buildings, in the chiseling of whose ornaments both taste and labor have been liberally expended, are decaying, in consequence of want of care in this particular. The Cathedral at Lichfield, and many of the Colleges at Oxford, are examples of this neglect, and also of the error of not building the stones in with their laminæ lying horizontally; from which cause the surface, in many instances, is detached in large flakes. At Agra and at Delhi the ornamental tracery of many fine buildings, including the Kootub Minar, is being fast obliterated, from the decay of the red sandstone in which it has been carved.

3. The qualities required in stone are so various, according to the nature of the building, that no very precise directions can be given, such as would exactly meet any particular case. Again, as any stone that admits of being quarried in suitable sizes, will suit for ordinary buildings, when neither great durability nor ornamentation are required, or for backing or filling in more important structures, for such work the Engineer need only consider the comparative cost between the varieties of stone procurable, or between stone and brick. If there are no quarries opened, a day's labor ought to be enough to satisfy any man of sense, whether the rock can be wrought or not at a reasonable expense. The following notes, therefore, refer to the better qualities of stone, and how they may be tested.

"The best" always means the best to suit; what would be required for a light-house or sea-wall would not answer for a highly finished architectural building or for a dwelling-house. The choice is in most cases further limited by the cost. Even the climate of the place may be an element in the calculation. Apart from all such collateral considerations, the question is reduceable to *strength*, *durability*, and *facility of working*. The two first are generally found together, but not necessarily so.

It is only in particular cases, such as for very large arches, that the resistance to actual crushing need be considered; the strength in this respect of even ordinary stone is greater than is generally required of it; and a

stone, of which the *durability* has been satisfactorily proved, may be safely trusted to resist pressure.

By *durability* is meant, the power to resist *weathering;* the wear and tear from atmospheric causes. Even a small deficiency in this respect will in time spoil the appearance, or even impair the stability, of the most carefully constructed edifice.

The third quality mentioned is in a manner negative; it is to a certain extent the inverse of the others; facility of being hammered or cut implies either softness in the substance of the stone, or a low degree of cohesiveness between the particles of this substance. It is a common puzzle in selecting a stone, to strike a medium between these conflicting qualities; a difficulty not altogether produced by the limitation of price, for the most enduring stone frequently does not admit of elaborate workmanship.

4. Stones Classed.—The stones used in building may be divided into three classes, each distinguished by the *earth* which forms its chief constituent. These are:—

I. Silicious Stones.
II. Argillaceous Stones.
III. Calcareous Stones.

5. I. Silicious Stones are those in which silica is the characteristic earthy constituent. With a few exceptions their structure is *crystalline-granular*, and the crystalline grains contained in them are hard and durable; so that weakness and decay in them generally arise from the decomposition or disintegration of some softer and more perishable material, by which the grains are cemented together, or by the freezing of water in their pores, when they are porous.

The following are the principal silicious stones used in building:—

1. *Granite* and *Syenite* are unstratified rocks, consisting of quartz, felspar, mica, and hornblende. The name *granite* is specially applied to those specimens in which there is little or no hornblende; the name *syenite* to those in which there is little or no mica; but both are popularly known as *granite.*

The quartz is in the from of clear, colorless or gray crystals; the hornblende (when present) in dark-green or black crystals; the mica in glistening scales, or grains composed of such scales; the felspar in compact opaque crystals, of a white, yellowish, or flesh color.

brick-making are infrequent; whilst for architectural purposes, the white marble of Jeypore, and the freestones of Agra, Delhi, Mirzapore and Chunar, are well known.

2. It is almost superfluous to say that the choice of stone for a building intended to endure for ages is of the very highest importance. Great numbers of beautiful buildings, in the chiseling of whose ornaments both taste and labor have been liberally expended, are decaying, in consequence of want of care in this particular. The Cathedral at Lichfield, and many of the Colleges at Oxford, are examples of this neglect, and also of the error of not building the stones in with their laminæ lying horizontally; from which cause the surface, in many instances, is detached in large flakes. At Agra and at Delhi the ornamental tracery of many fine buildings, including the Kootub Minar, is being fast obliterated, from the decay of the red sandstone in which it has been carved.

3. The qualities required in stone are so various, according to the nature of the building, that no very precise directions can be given, such as would exactly meet any particular case. Again, as any stone that admits of being quarried in suitable sizes, will suit for ordinary buildings, when neither great durability nor ornamentation are required, or for backing or filling in more important structures, for such work the Engineer need only consider the comparative cost between the varieties of stone procurable, or between stone and brick. If there are no quarries opened, a day's labor ought to be enough to satisfy any man of sense, whether the rock can be wrought or not at a reasonable expense. The following notes, therefore, refer to the better qualities of stone, and how they may be tested.

"The best" always means the best to suit; what would be required for a light-house or sea-wall would not answer for a highly finished architectural building or for a dwelling-house. The choice is in most cases further limited by the cost. Even the climate of the place may be an element in the calculation. Apart from all such collateral considerations, the question is reduceable to *strength*, *durability*, and *facility of working*. The two first are generally found together, but not necessarily so.

It is only in particular cases, such as for very large arches, that the resistance to actual crushing need be considered; the strength in this respect of even ordinary stone is greater than is generally required of it; and a

stone, of which the *durability* has been satisfactorily proved, may be safely trusted to resist pressure.

By *durability* is meant, the power to resist *weathering;* the wear and tear from atmospheric causes. Even a small deficiency in this respect will in time spoil the appearance, or even impair the stability, of the most carefully constructed edifice.

The third quality mentioned is in a manner negative; it is to a certain extent the inverse of the others; facility of being hammered or cut implies either *softness* in the substance of the stone, or a low degree of cohesiveness between the particles of this substance. It is a common puzzle in selecting a stone, to strike a medium between these conflicting qualities; a difficulty not altogether produced by the limitation of price, for the most enduring stone frequently does not admit of elaborate workmanship.

4. Stones Classed.—The stones used in building may be divided into three classes, each distinguished by the *earth* which forms its chief constituent. These are:—

I. Silicious Stones.
II. Argillaceous Stones.
III. Calcareous Stones.

5. I. Silicious Stones are those in which silica is the characteristic earthy constituent. With a few exceptions their structure is *crystalline-granular*, and the crystalline grains contained in them are hard and durable; so that weakness and decay in them generally arise from the decomposition or disintegration of some softer and more perishable material, by which the grains are cemented together, or by the freezing of water in their pores, when they are porous.

The following are the principal silicious stones used in building:—

1. *Granite* and *Syenite* are unstratified rocks, consisting of quartz, felspar, mica, and hornblende. The name *granite* is specially applied to those specimens in which there is little or no hornblende; the name *syenite* to those in which there is little or no mica; but both are popularly known as *granite.*

The quartz is in the from of clear, colorless or gray crystals; the hornblende (when present) in dark-green or black crystals; the mica in glistening scales, or grains composed of such scales; the felspar in compact opaque crystals, of a white, yellowish, or flesh color.

brick-making are infrequent; whilst for architectural purposes, the white marble of Jeypore, and the freestones of Agra, Delhi, Mirzapore and Chunar, are well known.

2. It is almost superfluous to say that the choice of stone for a building intended to endure for ages is of the very highest importance. Great numbers of beautiful buildings, in the chiseling of whose ornaments both taste and labor have been liberally expended, are decaying, in consequence of want of care in this particular. The Cathedral at Lichfield, and many of the Colleges at Oxford, are examples of this neglect, and also of the error of not building the stones in with their laminæ lying horizontally; from which cause the surface, in many instances, is detached in large flakes. At Agra and at Delhi the ornamental tracery of many fine buildings, including the Kootub Minar, is being fast obliterated, from the decay of the red sandstone in which it has been carved.

3. The qualities required in stone are so various, according to the nature of the building, that no very precise directions can be given, such as would exactly meet any particular case. Again, as any stone that admits of being quarried in suitable sizes, will suit for ordinary buildings, when neither great durability nor ornamentation are required, or for backing or filling in more important structures, for such work the Engineer need only consider the comparative cost between the varieties of stone procurable, or between stone and brick. If there are no quarries opened, a day's labor ought to be enough to satisfy any man of sense, whether the rock can be wrought or not at a reasonable expense. The following notes, therefore, refer to the better qualities of stone, and how they may be tested.

"The best" always means the best to suit; what would be required for a light-house or sea-wall would not answer for a highly finished architectural building or for a dwelling-house. The choice is in most cases further limited by the cost. Even the climate of the place may be an element in the calculation. Apart from all such collateral considerations, the question is reduceable to *strength*, *durability*, and *facility of working*. The two first are generally found together, but not necessarily so.

It is only in particular cases, such as for very large arches, that the resistance to actual crushing need be considered; the strength in this respect of even ordinary stone is greater than is generally required of it; and a

stone, of which the *durability* has been satisfactorily proved, may be safely trusted to resist pressure.

By *durability* is meant, the power to resist *weathering*; the wear and tear from atmospheric causes. Even a small deficiency in this respect will in time spoil the appearance, or even impair the stability, of the most carefully constructed edifice.

The third quality mentioned is in a manner negative; it is to a certain extent the inverse of the others; facility of being hammered or cut implies either softness in the substance of the stone, or a low degree of cohesiveness between the particles of this substance. It is a common puzzle in selecting a stone, to strike a medium between these conflicting qualities; a difficulty not altogether produced by the limitation of price, for the most enduring stone frequently does not admit of elaborate workmanship.

4. **Stones Classed.**—The stones used in building may be divided into three classes, each distinguished by the *earth* which forms its chief constituent. These are:—

I. Silicious Stones.
II. Argillaceous Stones.
III. Calcareous Stones.

5. I. Silicious Stones are those in which silica is the characteristic earthy constituent. With a few exceptions their structure is *crystalline-granular*, and the crystalline grains contained in them are hard and durable; so that weakness and decay in them generally arise from the decomposition or disintegration of some softer and more perishable material, by which the grains are cemented together, or by the freezing of water in their pores, when they are porous.

The following are the principal silicious stones used in building:—

1. *Granite* and *Syenite* are unstratified rocks, consisting of quartz, felspar, mica, and hornblende. The name *granite* is specially applied to those specimens in which there is little or no hornblende; the name *syenite* to those in which there is little or no mica; but both are popularly known as *granite*.

The quartz is in the from of clear, colorless or gray crystals; the hornblende (when present) in dark-green or black crystals; the mica in glistening scales, or grains composed of such scales; the felspar in compact opaque crystals, of a white, yellowish, or flesh color.

The durability and hardness of granite are the greater the more quartz and hornblende predominate, and the less the quantity of felspar and mica, which are the more weak and perishable ingredients. Smallness and lustre in the crystals of felspar indicate durability; largeness and dullness, the reverse.

The best kinds of granite are the strongest and most lasting of building stones. The difficulty of working them, caused by their great hardness, is only overcome by long practice on the part of the stone-cutters. Minute ornaments cannot be carved in granite, and a simple and massive style of architecture is the best suited for it. It is used chiefly in works of great magnitude and importance, such as light-houses, piers, breakwaters, and bridges over large rivers; and for such purposes it is brought from great distances at considerable cost, the stones being often cut to the required forms before leaving the quarry, with a view to save expense in carriage, and to obtain the benefit of the skill of stone-cutters accustomed to the material. It is only in districts where granite abounds that it is used for ordinary purposes.

2. *Gneiss* and *Mica Slate* consist of the same materials as granite, in a stratified form. They are found in the neighbourhood of granite, in strata much inclined, bent, and distorted, and often form great mountain masses. Gneiss resembles granite in its appearance and properties, but is less strong and durable. Mica slate is distinguished by containing little or no felspar, so that it consists chiefly of quartz and mica; it has a laminated or slaty structure, and the silky lustre of mica; it is a tough material in directions parallel to its layer, but is more perishable than gneiss. Both these stones are used for ordinary masonry in the districts where they are found. Gneiss, from its stratified structure, is a good material for flag-stones. Mica slate, split into thin layers, may be used for covering roofs; but it is inferior for that purpose to clay slate.

3. *Greenstone*, *Whinstone*, or *Trap* and *Basalt*.—These rocks are unstratified, and consist of granular crystals of hornblende or of augite, with felspar. In greenstone, the grains are considerably finer than in granite; in basalt they are scarcely distinguishable. Greenstone breaks up into small blocks; basalt into regular prismatic columns. They are found in veins, dykes, and tabular masses, amongst stratified rocks of various ages. Greenstone is usually dark green, rarely white or red; basalt nearly black. These varieties of color are due to the hornblende or the augite,

the felspar being white. Both these rocks are very compact, durable, hard and tough; they are well adapted for ordinary building, and specially well suited for paving and metalling roads.

4. *Talc, Chlorite Slate, Soapstone.*—In these stones, silicate of magnesia predominates. *Talc* is in transparent or translucent sheets of a laminated structure; it is soft and easily cut. *Chlorite Slate* is also laminated, soft, and easily cut, but more opaque than talc; it is sometimes used for roofing, but is inferior to clay slate. It has a green or greenish-gray color, and silky lustre. *Soapstone* is translucent and soft, and greasy to the touch. It is valued for its power of resisting the action of fire.

5. *Quartz Rock, Hornstone, Flint.*—These stones consist of quartz, pure, or nearly pure. *Quartz rock* and *Hornstone* are stratified, and appear to have been produced by the action of intense heat on sandstone; they are both compact. Quartz rock is crystalline; hornstone is glassy. They are the strongest and most durable of all stones; but their hardness is so great as to make their use in masonry almost impracticable.

Flint is found in nodules or pebbles scattered through the chalk strata and in beds of gravel, apparently left after the washing away of the chalk. It is hard and durable, but very brittle. Flints are used for building purposes by being made into a concrete with lime.

6. *Hornblende Slate* is hard, tough, durable, and impervious to water, and is used for flag-stones.

7. *Sandstone* is a stratified rock, consisting of grains of sand, that is small crystals of quartz, cemented together by a material which is usually a compound of silica, alumina and lime. In the strongest and most durable sandstone the cementing material is nearly pure silica; the weakest and less durable is that in which the cement contains much alumina, and resembles soft felspar or claystone. When there is much lime in the cementing matter of sandstone it decays rapidly in the atmosphere of the sea-coast, and in that of towns where much coal is burned; in the former case, the lime is dissolved by muriatic acid, in the latter, by sulphuric acid. *Calciferous sandstones*, as those containing much lime are called, pass by insensible degrees into sandy limestones. The appearance of strong and durable sandstone is characterized by sharpness of the grains, smallness of the quantity of cementing material, and a clear, shining, and translucent appearance on a newly broken surface. Rounded grains, and a dull, mealy

The durability and hardness of granite are the greater the more quartz and hornblende predominate, and the less the quantity of felspar and mica, which are the more weak and perishable ingredients. Smallness and lustre in the crystals of felspar indicate durability; largeness and dullness, the reverse.

The best kinds of granite are the strongest and most lasting of building stones. The difficulty of working them, caused by their great hardness, is only overcome by long practice on the part of the stone-cutters. Minute ornaments cannot be carved in granite, and a simple and massive style of architecture is the best suited for it. It is used chiefly in works of great magnitude and importance, such as light-houses, piers, breakwaters, and bridges over large rivers; and for such purposes it is brought from great distances at considerable cost, the stones being often cut to the required forms before leaving the quarry, with a view to save expense in carriage, and to obtain the benefit of the skill of stone-cutters accustomed to the material. It is only in districts where granite abounds that it is used for ordinary purposes.

2. *Gneiss* and *Mica Slate* consist of the same materials as granite, in a stratified form. They are found in the neighbourhood of granite, in strata much inclined, bent, and distorted, and often form great mountain masses. Gneiss resembles granite in its appearance and properties, but is less strong and durable. Mica slate is distinguished by containing little or no felspar, so that it consists chiefly of quartz and mica; it has a laminated or slaty structure, and the silky lustre of mica; it is a tough material in directions parallel to its layer, but is more perishable than gneiss. Both these stones are used for ordinary masonry in the districts where they are found. Gneiss, from its stratified structure, is a good material for flag-stones. Mica slate, spilt into thin layers, may be used for covering roofs; but it is inferior for that purpose to clay slate.

3. *Greenstone, Whinstone,* or *Trap* and *Basalt.*—These rocks are unstratified, and consist of granular crystals of hornblende or of augite, with felspar. In greenstone, the grains are considerably finer than in granite; in basalt they are scarcely distinguishable. Greenstone breaks up into small blocks; basalt into regular prismatic columns. They are found in veins, dykes, and tabular masses, amongst stratified rocks of various ages. Greenstone is usually dark green, rarely white or red; basalt nearly black. These varieties of color are due to the hornblende or the augite.

5. *Quartz Rock, Hornstone, Flint.*—These stones consist of quartz, pure, or nearly pure. *Quartz rock* and *Hornstone* are stratified, and appear to have been produced by the action of intense heat on sandstone; they are both compact. Quartz rock is crystalline; hornstone is glassy. They are the strongest and most durable of all stones; but their hardness is so great as to make their use in masonry almost impracticable.

Flint is found in nodules or pebbles scattered through the chalk strata and in beds of gravel, apparently left after the washing away of the chalk. It is hard and durable, but very brittle. Flints are used for building purposes by being made into a concrete with lime.

6. *Hornblende Slate* is hard, tough, durable, and impervious to water, and is used *for flag-stones.*

7. *Sandstone* is a stratified rock, consisting of grains of sand, that is small crystals of quartz, cemented together by a material which is usually a compound of silica, alumina and lime. In the strongest and most durable sandstone the cementing material is nearly pure silica; the weakest and less durable is that in which the cement contains much alumina, and resembles soft felspar or claystone. When there is much lime in the cementing matter of sandstone it decays rapidly in the atmosphere of the sea-coast, and in that of towns where much coal is burned; in the former case, the lime is dissolved by muriatic acid, in the latter, by sulphuric acid. *Calciferous sandstones,* as those containing much lime are called, pass by insensible degrees into sandy limestones. The appearance of strong and durable sandstone is characterized by sharpness of the grains, smallness of the quantity of cementing material, and a clear, shining, and translucent appearance on a newly broken surface. Rounded grains, and a dull, mealy

surface, characterize soft and perishable sandstone. The best sandstone lies in thick strata, from which it can be cut in blocks that show very faint traces of stratification; that which is easily split into thin layers is weaker. Sandstone is found in every geological formation above the primary rocks, amongst which its place is supplied by hornstone and quartz rock. The best kinds on the whole are those which belong to the coal formation; but they sometimes have their strength impaired by being divided into layers by extremely thin laminæ of coal.

The colors of sandstone are white, yellowish-red, and red, the latter colors being produced by the presence of peroxide of iron in the cementing material. Crystals of sulphuret of iron are sometimes imbedded in it; when exposed to air and moisture, they decompose, and cause disintegration of the stone. They are easily recognized by their yellow or yellowish-gray color and metallic lustre. Sandstone is in general porous, and capable of absorbing much water; but it is comparatively little injured by moisture, unless when built with its layers set on edge, in which case the expansion of water in freezing between the layers makes them split or "scale" off from the face of the stone. When it is built "on its natural bed," any water which may penetrate between the edges of the layers has room readily to expand or escape.

The better kinds of sandstone are the most generally useful of all building stones, being strong and lasting, and at the same time easily cut, sawn, and dressed in every way, and fit alike for every purpose of masonry.

6. II. Argillaceous or Clayey Stones are those in which alumina, although it may not always be the most abundant constituent, exists in sufficient quantity to give the stone its characteristic properties.

1. *Porphyry* consists of a mass of felspar, with crystals of felspar, and sometimes of quartz, hornblende, and other minerals, scattered through it. It occurs of all degrees of hardness. The variety in which the felspar matrix is soft and earthy, is called *claystone porphyry*; it is of little or no value for building purposes. The hardest kind, in which the matrix is compact and crystalline, and the whole material beautifully colored and capable of taking a high polish, is sometimes stronger than granite. It is rare, and is valued in building for ornamental purposes.

2. *Clay Slate* is a primary stratified rock of great hardness and density, with a laminated structure making in general a great angle with its planes of stratification. Its colors are bluish-gray, blue, and purple, the darkest

colors indicating in general the greatest strength and durability. It can be split into slabs and plates of small thickness and great area, and is nearly impervious to water; qualities which make it the best stony material for covering roofs, lining water-tanks, and similar purposes. The stronger kinds of clay slate have more tenacity along their laminæ than any other stone whose tenacity has been ascertained. The signs of good quality in slate are, compactness, smoothness and uniformity of texture, clear dark color, lustre, and the emission of a ringing sound when struck.

3. *Grauwacke Slate* is a laminated claystone, containing sand, and sometimes fragments of mica and other minerals. It is used for roofing and for flag-stones, but is inferior to clay slate.

7. III. Calcareous Stones, are those in which carbonate of lime predominates. They effervesce with the dilute mineral acids, which combine with the lime, and set free carbonic acid gas. By the action of intense heat the carbonic acid is expelled in the gaseous form, and the lime left in its caustic or alkaline state, when it is called *quicklime*. Some calcareous stones consist of pure carbonate of lime; in others it is mixed with sand, clay, and oxide of iron, or combined with carbonate of magnesia. The durability of calcareous stones depends on their compactness: those which are porous being disintegrated by the freezing of water, and by the chemical action of an acid atmosphere. They are, for the most part, easily wrought.

1. *Marble* is a compact crystalline carbonate of lime. It is found chiefly amongst the primary strata, and generally in the neighbourhood of igneous rocks. It is translucent, capable of a fine polish, sometimes white, and sometimes variously colored. It is one of the most durable of all stones. Its scarcity and value prevent its being used except for ornamental buildings.

2. *Compact Limestone consists of carbonate of lime, either pure, or* mixed with sand and clay. It varies in hardness and compactness, sometimes approaching to the condition of marble, sometimes to that of granular limestone. Its most frequent colors are white, grayish-blue, and whitish-brown. It is found amongst primary and secondary strata, and abounds specially in the coal and lias formations. It is very useful as a building stone, and is durable in proportion to its compactness.

3. *Granular Limestone* consists of carbonate of lime in grains, which are, in general, shells or fragments of shells, cemented together by some

compound of lime, silica and alumina, and often mixed with a greater or less quantity of sand. It is always more or less porous, and the less porous the more durable. It is found of various colors, especially white, and light yellowish-brown. In many cases it is so soft when first quarried that it can be cut with a knife. and hardens by exposure to the air. It is found in various strata, especially the oolitic formation. It there appears in the form of *Oolite*, or *Roestone*, so called because its grains are round, and resemble the roe of a fish. The pleasing color and texture of oolite and the ease with which it is wrought, have caused it to be much used in building, especially where delicate carving is required. The durability of oolites varies extremely. The Pórtland stone, the Bath stone, and the Aubigny stone (from Normandy) are examples of durable oolites. The perishable kinds of oolite decay more rapidly than almost any other stone, especially in an acid atmosphere.

4. *Magnesian Limestone*, or *Dolomite*, is found in various conditions, from the compact crystalline to the porous granular. In Britain it is found in the new red sandstone formation immediately above the coal. It is like limestone in appearance. Its durability depends mainly on its texture; when that is compact, it is nearly as lasting as marble, which it resembles in appearance; when porous, it is very perishable.

8. Indian Stone.—In the following paragraphs, are quotations from several pamphlets, returns, &c., published regarding building stons found in different parts of India.

GWALIOR SANDSTONE, from a pamphlet by Major-Genl. A. Cunningham, R.E.:—

1. *Ainthi Sandstone* —The Ainthi rock is the coarsest of the Gwalior sandstones; many of the grains of quartz being as large as mustard or opium seed. The usual colors are pinkish white, or ochreous yellow, with occasional short stripes or bars of black. The white rock, which is of less coarse texture than the other, is a very hard silicious schist. On account of its hardness, it is universally employed for the manufacture of corn-mills, which are largely exported to the Gangetic Doab, and to all the districts south of the Jumna. The stone is occasionally quarried for beams and thick slabs, for which it is well adapted by its superior strength, but its extreme hardness and consequent difficulty of being worked completely prevents its use, excepting only in the villages immediately surrounding the quarries.

2. *Paraoli Sandstone.*—This is a very hard, fine grained, compact white sandstone, with very little, if any, admixture of clay. It is used both for beams (*tir*) and for long thick slabs (*patti*), for which purpose it is considered superior to all the other Gwalior building stones.

3. *Telri Sandstone.*—This is the finest grained, hardest, and strongest of all the

Gwalior sandstones. Its color when fresh broken is a dull blue-green, which gradually changes to olive-green. It is never used by natives on account of its extreme hardness, which destroys their tools in working it. The verandah of the Residency is paved with slabs of this stone, which were once polished, but the polish is not lasting. It is comparatively soft when first quarried, but it soon acquires great hardness from exposure to the air.

4. *Bamor Sandstone.*—Bamor is one of the principal quarries for the supply of Gwalior with building stone, on account of its easily accessible situation on the high road. The stone is readily quarried into slabs of various thickness, owing to the natural cleavage of the rock, which is of a dirty white color, marked with orange specks. It is considered the best stone for slabs, as it will bend nearly half an inch before it breaks. It is also used for beams and thick roofing slabs which are quarried of a large size; the first 15 feet long, with a breadth of 9 inches, and a depth of 24 inches; the latter 12 feet long, with a breadth of 18 inches, and a depth of 6 inches.

5. *Kulhet Sandstone.*—Kulhet sandstone is exactly like that of Bamor, with the addition of thin laminæ of mica, which determine the lines of cleavage for slabs. It is, however, a softer stone than the Bamor, and is, therefore, used for making lattice work, a purpose for which it is well adapted.

6. *Manpoor Sandstone.*—This stone is of a dingy pink color, but of a good close texture. It is soft and easily worked, and is therefore used for statues, and for small building stones. Its strength, however, is so inferior that it is never used for beams, but is chiefly in demand for cornices and carved work of all kinds.

The following Table exhibits the results of experiments on the above, collected together for comparison:—

No.	Quarries.	Specific gravity	Weight of 1 cubic foot lbs.	Values of p for cross strain
1	Ainthi, ...	2·284	142·95	156·12
2	Paraoli, ...	2·277	142·50	99·00
3	Telri, ...	2·519	159·50	189·40
4	Bamor, ...	2·368	148·20	85·10
5	Kulhet, ...	2·387	149·40	104·31
6	Manpoor,...	2·359	147·63	50·22

9. The following extracts are from the Memoirs of the Geological Survey.

MIDNAPORE AND ORISSA.—The rock most generally employed for building purposes in these districts is *Laterite*. This is largely used in the construction of the walls of houses, and in buildings also of greater pretension. Few rocks present

greater advantages from its peculiar character; it is easy to cut and shape when first dug, and it becomes hard and tough after exposure to the air, while it seems to be very little acted on by the weather. Indeed in many of the sculptured stones of some of the oldest buildings, temples, &c., in the district, the chisel-marks are as fresh and sharp as when first built. It is, perhaps, not so strong, nor so capable of resisting great pressure, or bearing great weights, as some of the sandstones, or the more compact kinds of gneiss, but it certainly possesses amply sufficient strength for all ordinary purposes. It is largely used at the present time, but has also been employed from the earliest period from which the temples and buildings of the country date. And the elaborate specimens of carving and ornament, which some of these present, show that nodular structure and irregular surface of the laterite do not prevent its effective use for such purposes of ordinary ornamentation, as mouldings, &c. Another advantage it possesses over other rocks is the facility of transport, it being generally found in the low grounds, and often at no great distance from some of the many streams which traverse the vicinity.

Slabs from four to five feet long are easily procurable of this rock. They are quarried in a rude but effective way; a groove is cut with a rudely pointed pick round the slab; another is made underneath, and then a few wedges driven in split off the block. The more loose and gravelly forms of the laterite are universally used for road-metal, for which purpose they are admirably adapted.

In Orissa, *Gneiss* and *Sandstone* are also quarried in places for building purposes. Ancient sculptures on both are found. The caves of Khundegerce, and the temples of Bobanessur are both of sandstone, while temples with statues of Hindoo deities carved in gneiss are common in many districts. The variety generally worked is one of the kinds of garnetiferous gneiss. At Neeltigur, mill-stones are manufactured, to a considerable extent; in other places drinking cups are made of gneiss.

The chloritic and serpentinous beds in the gneiss are manufactured into plates and basins, wherever they occur. In Midnapore district, and close to its boundary, in Maunbhoom, and in the Nilgiri hills, are the principal seats of manufacture in these districts The rock yields a beautiful compact and very tough material, though soft and easy to work. It is admirably suited for fine carvings, as may be well seen in some of the beautifully sculptured doorways of the Black Pagoda, which are carved from this variety of rock. Blocks of almost any size can be obtained, the only impediment being the difficulty of transport from the high hills on which it generally occurs.

10. TRICHINOPOLY AND SOUTH ARCOT.—The only buildings, properly so called, for which stone is employed by the natives, are the lower portions of the large native temples, for which gneiss alone is used, whatever be their situation; and the small village *korils* and *chuttrums* (or native rest-houses), which are constructed usually of the stone nearest at hand, on the cretaceous rocks, generally of some form of limestone. A large quantity of roughly hewn stone is also employed by the natives for revetting the inner slope of the larger tank bunds, and for constructing the *kalingulas*, or waste-weirs, as well as for walling the large rectangular irrigation wells or *bowlies* when sunk in loose ground.

The *Cretaceous Limestones* through not very durable are quarried to a considerable extent, for the construction of small village *pagodas* and *chuttrums*. The chief locality from which stone for this purpose is procured, is the ridge at the base of the

Octatoor group, which extends from Parawoy to Vylapaudy; much is also obtained from the ridges of coral-reef and sedimentary limestones, similarly situated, at Assoor, Maravuttoor, Cullpaudy, Sirgumpoor, Varagaupady, and many other places further, to the southward. The ridge of shell limestone at Garoodamungalum and Alundanapuram, is another favorite locality, and indeed wherever a band of limestone or calcareous grit crops out, heaps of fragments and lines of wedge holes show that the spot is occasionally resorted to by the native quarrymen.

These limestones are of various degrees of purity. Specimens of the coral-reef limestones, analysed by Mr. Tween, gave from 95 to 98 per cent. of carbonate of lime. The Olapaudy limestone, is somewhat less pure, and some of the calcareous grits, such as those in the upper part of the Octatoor group, between Kolokhaunutum and Shutanure, do not contain probably more than 20 per cent. of calcareous matter. The coral-reef and purer sedimentary limestones are tolerably compact, but, as may be seen in the coping stones and drip stones, and the exposed mouldings of *kovils* built of these rocks, they are but ill qualified for exposed exteriors, where they rapidly yield to the heavy tropical rains. These stones being soft, and easily worked, are used to a considerable extent by the natives of the district for rice-mortars and water troughs.

The *Sandstones* of the Cuddalore group are quarried to a small extent at Velur, near Verdachellum, and at Vellumpaleyan, on the bank of the Guddalum. The stone is compact, moderately fine in grain, and being jointed in two directions, is easily quarried. It is worked for the household purposes above-mentioned, and is also used to some extent for dry walling The mile-stones on the roads about Verdachellum are also made of this stone. It appears to be well adapted for building, but I am not aware that it has ever been employed for this purpose.

Laterite is largely used for building wherever it occurs. Its chief localities are at Vullam in Tanjore, and Strimustrum, in the N.E. of Trichinopoly. I have also noticed it at several places between Tangore and Trichinopoly, and at Andanapet, to the east of Verdachellum, and it probably covers a great part of the Cuddalore sandstones concealed beneath the red soil. At Vullam it is cut with a chisel pointed crowbar, into blocks 2 feet 6 inches long, 1 foot wide, and 6 inches thick. It is when first extracted, a flaky ferruginous sandy clay, and rather friable, but when exposed for some months to the action of the rain and sun, as is usually the case before it is used for building, it hardens and becomes covered with a dark polished encrustation of hydrated oxide of iron, which protects it from further change, and resists the decay of the stone, however long it may be exposed. At Vullam it is much used by the natives in building their houses, in preference to brick, and the Vellaur annicut at Chetia-tope, near Bhonagiri, is built in part of this rock quarried at Strimustrum.

11. NEELGHERRY HILLS.—Almost the only article of any economic value furnished by the crystalline rocks of the Neelgherries is stone, whether for the purposes of building or road making. The various forms of the gneissose rocks are abundantly obtainable for either of these purposes, but for the former they have been hitherto extremely neglected, the only building in which stone has yet been employed being a private house in Ootacamund, which, from its singularity in this respect, is generally known as "Stonehouse." The reason for this preference of brick over stone is undoubtedly its comparative cheapness; the advantages of the superior durability of the latter material and, what on the Neelgherries is a matter of no small importance—its dryness—have been sacrificed to a present saving in cost.

In many parts of Mysore, the foliated rocks exhibit a great tendency to scale off in large slabs, varying from a few inches to one or two feet in thickness; and as this variety of the rock is very free from vertical joints, long narrow post-shaped blocks and slabs of various sizes, are readily cut by means of a row of iron wedges driven into holes previously cut with the chisel.*

On that part of the hills east of Billicul, which overlooks the Mysore country, *gneiss* of somewhat similar structure occurs; and again on the Lovedale flank of Elk Hill, near Ootacamund; in the Kaitee valley; and very extensively on the northern escarpment of the Dodabetta range. In these localities, the slabs are in most cases much thicker than those quarried in Mysore.

The rocks of the Neelgherries are but rarely well jointed, and when they are so the stone appears to have a greater tendency to decompose in consequence. There are, however, one or two localities on the Coonoor road where the rock is advantageously jointed for quarrying purposes, and large blocks of a more or less rectangular form might be obtained The gneiss of the Kundahs, especially in the neighbourhood of Sispara, is very finely jointed, but the great distance of that locality from the inhabited part of the hills and difficulty of transport, preclude the possibility of working the stone profitably.

By far the most valuable of the crystalline rocks described in this memoir is the *Limestone* near Coimbatoor, which was first discovered by Dr. Cornish, the Civil Surgeon at Coimbatoor. This stone might not only be employed for the manufacture of lime of great purity, but moreover owing to its softness and its non-liability to decompose, might be advantageously used as building stone, except for such parts of a structure, as present sharp angles, and are at the sometime exposed to much mechanical wear. Being moreover susceptible of a high polish, and very transparent, it would afford a very beautiful material for internal decoration, the effect of which would be enhanced by the judicous selection of slabs of various tints. Pink and gray occasionally approaching white, are the prevailing colors of the stone.

12. MADRAS STONES.—From the Indian Journal of Art, Science, and Manufacture for 1856.

Granites.—The granites occur of three distinct periods of formation; the oldest being composed of very large masses or crystals of felspar, quartz, mica and hornblende. In many parts of southern India these granites form the low undulating rounded hills or level country at the base of the hills. The felspar and mica are for the most part decaying and soft, the quartz and hornblende are little altered. These granites have been followed by the upheaving of a small grained series, composed chiefly of sienites and pegmatites, which are of a more compact and durable nature. Many of the rocks of this class are very ornamental and well suited for building purposes. In some localities they partake of the tabular character of gneiss, but are often destitute of mica. The most recent granites are of a still finer grain, and in a few localities they resemble sandstones, but the constituents can be detected with the aid of a lens, the felspar being in smallest proportion and the quartz and mica in excess.

Trap and Greenstone.—Nearly allied to this last class, are the trap, quartzose and

* In Mysore the electric telegraph wire is supported on stone posts of this description upwards of twenty feet in length, and averaging about nine inches square in section.

greenstone rocks, which are very numerous and pass into each other. Rocks of this class are much used by the natives for building and paving purposes.

Sandstone and Whetstone.—A very widely disseminated class of formations belonging to the transition periods are the sandstones, grits, whetstones, slates, and soft shales, resembling Tripoli. These occur in very great abundance along the base of the Eastern Ghats, and in most of the ranges of granite hills in Mysore, Cuddapah, and the Ceded Districts. In some localities, as in south Arcot, Nellore, and Cuddapah the beds of sandstone are of enormous thickness, yielding freestones, whetstones, and polishing shales of every variety of color and hardness. In the Nellore district, the sandstones are impregnated with emery and iron ore; at Vellore and parts of the Ceded Districts they are of a slaty fracture, hard and silicious; at Sadras, Tripetty, Cuddapah, Bangalore, Soondoor, and Kaludgee, they are of a softer nature, being frequently associated with Tripoli. At Sadras the sandstones are accompanied by alluvial ochrey pumice and bituminous wood.

Slates.—The slates of southern India are for the most part coarse, soft and aluminous. A blue slate well suited for paving purposes and for cook-room tables, occurs near Cuddapah. Green alum slate occurs at Woontimettah, and hard black and yellow slates containing large quantities of iron pyrites at Nundial, and near Kurnool, in the Ceded Districts.

Diamond Sandstone and Breccias.—Another interesting class of formations nearly allied to the last are the diamond sandstones and breccias. These cover large tracts of country in the Masulipatam, Hyderabad and Cuddapah districts. The sandstones are mostly fine grained, hard and quartzose, being frequently coated by layers of iron ore and sesquioxide of manganese. The breccias are often very hard and of all shades of color.

Magnesian Minerals.—Magnesite, steatite, and serpentine are abundant in several districts. Precious serpentine occurs near Seringapatam, and in small quantities along with the softer kinds at Chittoor.

Marbles.—Marbles and compact limestones are found in great abundance in southern India. The large grained, primitive, and highly crystalline varieties at Courtallum, Tinnevelly, Salem, Madura and Nellore.

Limestones.—The fine grained, compact, secondary limestones occupy extensive tracts of country through the Ceded Districts, Guntoor, Masulipatam, Hyderabad, and the Southern Mahratta country. Fossil limestones are found at Cape Comorin, Ootatoor, Pondicherry, Seedrapett, Trivacarey and Sadras. Varieties of blue, gray, and black mountain limestones occur in several parts of the Presidency.

13. The Rajmehal hills in Bengal, the rocks of Central and Western India, and many other localities also contain many varieties of stone suitable for building purposes, but there are no detailed accounts of them available.

PUNJAB STONES.—(From Report of the Punjab Exhibition of 1864).

From Sahi Balabgarh, in the Delhi district, there is a good collection of building materials, which includes the red, the spotted and the light-colored sandstone, so much used in the large buildings of Hindoostan; and from the same place are polished blocks of white marble, and of a pretty dappled gray marble (called Narnaul marble) which last is also exhibited from the Hissar district.

From the Kangra district there are gray limestone, sandstone of two sorts, (both good for building,) and granite. Sent from Madhopore, is some nice workable sandstone which must come from the hills, above that place. From Kashmere there is some black marble and some polished slabs of serpentine, which is found at Tashgám in little Thibet.

From the Salt Range (Jhelum and Shahpoor districts) there are good building stones, sandstone and calcareous sandstone ; from Jhelum are specimens of marble which *might become useful for building ; among this series must be* counted the gypsum or alabaster of the same hills (sometimes wrongly labeled soapstone, or marble). The harder varieties of this might be used for interior decorations, while the general run is fit for making plaster of Paris, of which there is one specimen from Shahpoor. From Dera Ismael Khan, there is only some soft white limestone, from Kohat a cellular limestone, used in rubble masonry ; while from Attock are two or three kinds of stone, calcareous sandstone, a variegated limestone, granite and sienite ; there is *also yellow marble from Peshawur, and argillaceous limestone from Abbottabad.*

The series of slates exhibited are very fine. There is one immense slab, 12 feet long, from the Dalhousie quarries. The slates are some of them mixed and veined like marble ; they are generally of a bluish-gray tint not inclining to purple, nor have they the fine texture of Welsh slates, being much more schistose. They are used universally in the hills both for flooring and roofing purposes. The cutting of slates for roofing purposes is somewhat costly, and even at the quarries they fetch a high price.* Occasionally they are brought to the plains, when an enterprizing contractor undertakes such a task, otherwise slate is but seldom met with.

In the Khuttuk hills, on the N. W. frontier, and in the Curruckpore hills, in Bengal, excellent beds of slate are also found, suitable for flooring or roofing.

The *Sylhet limestone* in the Khasia hills (N.E. Bengal) is well known, but it is principally used for burning into lime.

The *Red sandstones* of Agra and Bhurtpore were much used by the old Moghul builders at Delhi, Agra, &c., and being easily worked and durable are very suitable for ornamental architecture.

The *Quartzose Rock* of Delhi is a most durable and valuable building material, although very intractable. The famous "Kootab Minar," now more then six centuries old, gives satisfactory evidence of the durability of the material of which it is composed. The body of the pillar is made up of the strong quartz rock found abundantly in the neighbourhood, and which, from its compactness and highly crystalline character, shielded as it is, moreover, from direct atmospheric influence, will remain undeteriorated till the outer shell has been reduced to dust. It is encased in sandstone of a fine and equal grain, very much resembling in this respect

* As high as Rs. 8 per 100.

the Bhurtpore and Roophas stone. It is liver colored, with numerous, *chiefly round, cream-colored spots, proceeding from the section of a* spheroidal mass of that color.

14. The greater portion of Central and Western India is covered by an immense overflow of trap, so extensive indeed as *to embrace on area of* something like 160,000 square miles (about the size of France). *Trap* or *basalt* (vide *ante p.* 4) is an augitic lava generally consisting of about 46 silica, 16·5 alumina, 9 lime, 20 oxide of iron, and 3 or 4 soda. *Trachyte* is a felspathic rock. Between trachyte and basalt are innumerable varieties depending on the proportions of augite and felspar, and on the admixture of olivine, oxide of iron, hornblende, quartz, and many other minerals. Trap or basalt is largely used in Bombay; it can be obtained in large blocks: those prepared for the lighthouse are 25 cubic feet, and weighing nearly 3 tons. A description of the masonry in this trap country is given by Mr. Horace Bell, C.E., in an article in the "Professional Papers on Indian Engineering," [Second Series, Vol. I.,] from which the following remarks are extracted.

It would be difficult to give any general description of the appearance of trap. It includes a great variety of different looking and differently valuable rocks of all colors and degrees of hardness. One may see yellow trap (Coorla, Bombay,) blue, red, pink, green, gray and spotted (amygdaloid;) but I need not say that color is no guide to the engineer in selecting a stone. Neither, indeed, is locality; for one ridge within a square mile may yield a stone which will disintegrate almost literally into mud in the first monsoon, while another ridge close by may afford a stone such as I have seen in some old temples on which the tool marks are clearly seen after being built about 1200 years. In effect, the selection of stone for a work of any permanence, or that more particularly has to carry a heavy load, is one of the most responsible duties of the engineer in a trap country. Generally, the hardest stone may be assumed to be the most durable, though this is not always the case; as for instance *basalt which has a columnar structure, may come out of a quarry seemingly hard* enough for any work, but which will be in fragments in perhaps a few months after exposure. The prominent feature in trap or basalt is its hardness, and what may be called intractability, and it is this that, making it so cruelly difficult and expensive to work, tempts both contractor and engineer to seek a soft and frequently unreliable stone. With but few exceptions, I have noticed, that the cellular and amygdaloidal traps are the most liable to disintegration, so also are those that have a rusty gray color* on fracture. The best, I should consider, to be the blueish green basalt, which is very hard and heavy, having a specific gravity about 3·00, and which rings like a metal on being struck. But, as I have before said, there is no reliable guide in color or appearance, and the only safe test is the old one of finding out old buildings and quarry faces. Failing these, which may not be always found, one must trust to the

* From oxide of iron.

experience of others, or to chance to settle the matter. It would be useless here to give the names and characters of the very numerous rocks which we may include under the term *trap*. It is sufficient for us to recognise the fact of the great number of different materials to be found in the trap area, and to be wary in using any one that has not established a character already for durability.

I give here a small table of some experiments I made to determine the absorption of some kinds of trap rock compared with other well known materials.

Kind of Stone.	Weight of stone specimen (dry) in grains.	Actual absorption of water after having immersed in grains.		Relative amount of water absorbed after.	
		1 hour.	3 hours.	1 hour.	3 hours.
Green black basalt (Khundwa) very hard, ...	2598	10	No increase.	[illegible]	..
Light gray, ditto, ditto,	1557	11	14*	[illegible]	[illegible]
Yellow trap, Coorla, Bombay, ..	706	30	No increase.	[illegible]	..
Red Amygdaloid, Pokurnee, G. I. P. Railway, ...	1856	90	do.	[illegible]	..
Piece of fair red brick made at Khundwa, ...	1531	244	do.	[illegible]	..
Piece of Stock brick, English,	453	40	73*	[illegible]	[illegible]
Piece of neat Portland cement mortar, ...	698	122	146*	[illegible]	[illegible]

tion of sulphate of soda, and weigh the fragments so detached from a block of a given size and surface in a given time.

The only sure test, however, of the durability of any kind of stone, is experience; and the engineer who proposes to use stone from a particular stratum in a particular locality, in any important structure, should carefully examine buildings in which that stone has been already used, especially those of old date.

The great difference which may exist in the durability of stones of the same kind, and presenting little difference in appearance, is strikingly exemplified at Oxford, where Christ Church Cathedral, built in the twelfth or thirteenth century, of oolite from a quarry about 15 miles away, is in good preservation, while many Colleges only two or three centuries old, built also of oolite, from a quarry in the neighbourhood of Oxford, are rapidly crumbling to pieces.

The effect of diversities of *climate* also is exhibited in the present condition of the Obelisk of Luxor, which, brought from upper Egypt to Paris, has become blanched and full of small cracks during the forty years it has stood on the Place de la Concorde: although forty centuries had not perceptibly affected it as long as it was in Egypt.

16. Preservation of Stone.—The decay of all natural building stones is the combined effect of various causes:. dust, spiders webs, the action of rain, *Lepra antiquitatis*, (a minute lichen, which is one of the worst enemies of stone), hasten the decay of stone, especially of those parts where any sculpture or ornamental carving promotes the deposition of dirt and dust. The various processes which have been tried or proposed for the preservation of naturally perishable stone, all consist in filling the pores of the stone at and near its exposed surface with some substance which shall exclude air and moisture. In every case the surface of the stone should be prepared to receive the preserving material, by expelling the existing moisture as completely as possible; and this is easily done by the aid of a portable furnace containing burning coke or charcoal. The principal preserving materials are the following:—

Bituminous matter, such as coal tar, is very efficient, but unsightly from its color. It is possible, however, that a colorless or light-colored bituminous substance, suited for the preservation of stone, might be prepared by dissolving "paraffine" in pitch-oil, or by some such process.

Drying Oil, such as linseed oil, either unmixed, or as an ingredient of

paint, protects the stone *for a time*; *but it is gradually destroyed* by the oxygen of the air, so that it requires renewal from time to time; and it injures the appearance of the stone.

Silicate of Potash, or soluble glass, is applied in a state of solution in water, either alone or mixed with silica in fine powder. It gradually hardens, partly through the evaporation of its water, and partly through the removal of the potash by the carbonic acid of the air.

Silicate of Lime is produced by filling the pores of the stone with a solution of silicate of potash or soda, and then introducing a solution of chloride of calcium, or of nitrate of lime. The chemical action of the two solutions produces silicate of lime, which forms an artificial stone, filling the pores of the natural stone, together with chloride of potassium or nitrate of potash, as the case may be, which salts, being soluble in water, are washed out.

The efficiency of the last two processes, and of various modifications of them, *has of late been much contested. Time and experience only* can show their real merits.

Black Oxide of Copper and its salts have been used *in many places*, and the length of time which has elapsed since their application seems to warrant the conclusion that their compounds acts as preservatives of stone.

17. Artificial Stone.—The idea that stone could be cheaply produced by artificial means, and moulded to any form required has gradually forced itself upon the minds of modern inventors, and has borne fruit in a large number of processes more or less practical and adapted to secure the end in view: which however can be but briefly noticed here by the mention of one or two only of the various methods in use. Perhaps the best known of them is the celebrated Ransome process. Ransome's patent silicious stone has been lately imported into Bengal, and used in the Nawab's new *palace at Moorshedabad, where its beauty and utility* have been highly commended.

The *following is* an account of the process of manufacture: (which was lately regularly carried on in Bombay, by Mr. Pye Smith, Ransome's Agent, in the Reclamation Workshops, and the stone used for mouldings of the Post office and other public buildings):—

The material is made, by preference, of finely sifted dry sand. A small proportion of pulverized stone is added to the sand, to give the silicate of lime produced in the manufacture the necessary closeness of surface for

its cementing action. To every bushel of the mixture about one gallon of prepared silicate of soda (melted flint) is added, and the whole mass is then thoroughly mixed and incorporated in a simple mill, from which it is taken—a putty-like plastic substance—in a fit condition for the moulds. The mixture of each charge of the mill occupies only from three to four minutes, and is remarkably complete.

The moulding is, for the greater part, done in wooden moulds, but in some cases metal, and in others plaster of Paris is employed. The prepared mixture is pressed into the mould by means of suitable tools provided for that purpose. A peculiarity of this material is, that mouldings retain the precise form in which they emerge from the mould, without enlargement, contraction, cracking, or warping, which is not the case with *materials that are burnt.*

The men, when they have taken their work from the moulds, place it upon a bench, where by means of a flexible hose, it is drenched with a solution of chloride of calcium, in a cold state. The chloride of calcium acts rapidly upon the silicate of soda, and solidifies the mass. The castings are next conveyed upon trucks to the adjoining room, where they are immersed in cisterns containing a solution of chloride of calcium having a specific gravity of about 1·4, and a temperature of about 212°. The chemical action between the silicate of soda and the chloride of calcium is consummated in this stage, and results in the formation of what is thought to be an insoluble silicate of lime, which envelopes and joins all the particles of sand, gravel, chalk, detritus of stone, or other mineral base, of which the block or casting is composed. After the work has been thoroughly saturated by the boiling calcium, all that remains to complete the process is to wash away the chloride of sodium, or common salt, which has been evolved by the combination of the sodium with the chloride. This is done by means of troughs with perforated bottoms, that discharge a copious shower-bath upon the castings. This part of the process must be very carefully carried out, for, if a stone saturated with Chloride of Sodium is allowed accidentally to dry, it will immediately split up: and if this salt be not thoroughly removed by the washing process from the stone before it is allowed to leave the factory, the surface of the stone will disintegrate.

Some experiments have been made to show the strength of the concrete stone, as to its power to resist both pressure and tension. A 4-inch cube,

made fourteen days previously, remained intact under 35 tons, and was crushed by 40 tons. A second cube, of the same size and age, was damaged at the edges by 35 tons, and was crushed by 44 tons. Of its strength, however, there is no doubt. The question, of course, is what effect long exposure to atmospheric changes and the weather may have.

In the manufacture of this stone at Bombay by Lieut Ducat, R.E., the best results were obtained by adding 6 parts of sand to 2 parts of white clay or moorum. This was mixed in a Ransome's mill for 10 minutes, moulded, and immersed in chloride of calcium for 40 hours, boiled for 4 hours, and allowed gradually to cool. It was then washed for 72 hours in running water and dried.

There seems no reason to doubt that this material could be successfully prepared in numerous localites in India: but the question of cost has not been yet satisfactorily solved. Up to 1870 the stone made at Bombay, had been turned out at a rate of Rs. 8-8 per cubic foot, but Mr. Pye Smith, was of opinion, that it would hereafter be made for Rs. 5 per cubic foot. At this rate, however, it could not compete with the natural stone at Bombay.

The process invented by M. Sorel, a celebrated French Chemist, produces also most satisfactory results. It is a sand concrete, having for its basis the use of oxychloride of magnesium (a new cement discovered by M. Sorel).

The process of making stone by this method is as follows:—natural Magnesite—Carbonate of Magnesium—is first calcined, which reduces it to the oxide of magnesium. In this state it is mixed dry in the proper proportion, by weight, with the powdered marble, quartz, sand, or whatever material forms the basis of the stone. It is then wetted with bittern water, which converts the oxide of magnesium into the oxychloride. The now semi-plastic mixture is rammed into moulds, where it speedily hardens sufficiently to be taken out and laid on skids. In two hour's time the stone is so hard, that the heaviest rain will not wash the corners off, and in from a week to two weeks the stones may be marketed and used. These stones are, according to good authority, capable of withstanding even more severe weather tests than natural stones.

The *Victoria Stone* is a new kind of artificial stone invented by a clergyman, the Rev. H. Highton. The process by which it is made consists in mixing broken granite with hydraulic cement, and steeping

the whole, when set, in a solution of silica. The granite used is the refuse of the quarries, and is broken up at the works. It is then mixed with Portland cement, in proportions of four of granite to one of cement, sufficient water being added to give it a pasty consistency. In this state it is placed in moulds, when it consolidates in about 4 days. When taken from the moulds it is placed for 2 days in a solution of silicate of soda which completes the process.

The silicate solution is prepared in a peculiar manner, and upon it the success of the operation depends. The silicate of soda has the property of hardening any kind of concrete in which lime is a component. This substance has been hitherto too costly for general use in artificial stone manufacture, and it becomes caustic by the absorption of its silica, so that it attacks the hands of the workmen.

Mr. Highton produces his solution in the following manner. He uses a soft kind of stone, containing 25 per cent. of silica, found at Farnham, in Surrey, England. This stone readily dissolves in a cold caustic soda solution.

The solution of soda is placed in the tanks used for steeping the stone, and the Farnham stone is ground and added to the bath. The lime in the artificial blocks removes the silica from the solution, which in its turn takes up more silica from the Farnham stone, and so maintains its supply of silica, thus removing the objections above named.

The process is extremely ingenious, and flagging, sinks, mantels, coping, cap-stones, sills, &c., are produced by it. Finely cut mouldings are not successfully produced, and it seems better adapted to a heavier class of work.

18. **Quarrying.**—The Engineer may be so situated in this country that he may require to quarry and raise his own stone; the following observations will therefore be useful. The stone found near the surface, which has been exposed to the atmosphere, is not so sound as that below, where it has been subjected to pressure, and where consequently it will be of greater density. On opening a quarry, the first consideration is how to raise and deliver the stone in the least expensive manner. The work should therefore not be begun too low, but an excavation made in the side of a hill, in preference to the top, that the road leading to and from it may be as gentle as possible. When necessity compels the after-delivery from below, a gentle descent should be cut to it, to assist the draught of the animals employed, if machinery be not available.

that is offers least resistance to the force of the powder. The *tamping bar* is a heavy brass rod, of a diameter a little less than that of the hole in which it is to be used, and slightly tapering at the extremities. At each end, an open groove is formed along the side, to admit of the bar being used with facility, while the *needle*, to be described immediately, is placed in the hole. Brass is selected for tamping bars, to avoid the risk of accidents from the charge being ignited by sparks, which would be struck were iron or steel to be employed. In using the bar, the tamping material is put into the hole, in small quantities, sufficient to fill from an inch to an inch and a half at a time, and each is well and firmly rammed home by successive blows. The time required varies with the material used, and the quality of the tamping depends much on the dexterity of those employed.

Through the tamping, it is necessary that a communication with the charge, for the purpose of priming, should be made. This is done by means of the *priming needle*, which is a thin metal rod having a loop handle at one extremity, and pointed at the other. Copper is a bad material for priming needles on account of its softness; those of iron about 1-16th of an inch in diameter answer better, and to guard against accident by sparks being struck by them, they may be tipped with brass. In using the needle, it is necessary to grease it well before the tamping is commenced, and to turn it frequently during the process, since the friction ultimately becomes so great, as to cause nearly half the time required for tamping to be consumed in withdrawing the priming needle.

The space occupied by the priming needle is filled with fine powder (which is sometimes confined in a straw or fine reed) and which is fired by means of a slow match, made of paper or linen soaked in a strong solution of nitre or gunpowder; and this must be so arranged as to give the person firing it time to retreat before the powder explodes.

If *Bickford's fuze* can be procured it is much safer and should invariably be used: in this case the priming needle is not employed: the fuze being placed in the centre of the bore while the tamping is rammed home round it. In extensive operations, when a heavy charge or series of charges is to be fired, the voltaic battery* is now generally employed. A good blast should produce a smothered (not a loud) report, and the mass of rock should be thrown down without being blown into fragments.

* See "Blasting under water" Vol II., Second Edition from p. 779, &c.

20. Upon the judicious selection of the position of the holes will in a great measure depend the useful effect of the blast: but two leading errors are committed by quarrymen or miners in general, viz., selecting an injudicious position for the charge, by which the action of the powder is exerted in the direction of the opening where it was introduced; and the adopting as a rule for the several charges, to fill a certain number of feet or inches of the hole bored, usually one-third of its depth, instead of employing given weights adapted to the *lines of least resistance.*

The *line of least resistance* is that line by which the explosion of the powder will find the least opposition to its vent in the air. This need not necessarily be the shortest line to the surface: as for instance, a long line in *earth* may, from the same charge, afford less resistance than a shorter line in *rock.* Supposing the material in which the explosion is to take place, be of uniform consistence in every direction, charges of powder to produce similar proportionate results ought to be as the *cubes* of the lines of least resistance, and not according to any fanciful depth of hole bored. Thus, if 4 ounces of powder would have a given effect upon a solid piece of rock of 2 feet thick to the surface, it ought to require 13½ ounces to produce the same effect upon a piece of similar rock 3 feet thick; that is—

	Cube of 2 feet (line of least resistance.)		Charge of powder in ounces.		Cube of 3 feet (line of least resistance.)		Charge in ounces.
as	8	is to	4	so is	27	to	13½

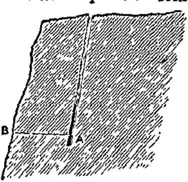
or, what is the same thing, half the cube of the line of least resistance expressed in feet, will, *on this particular datum*, be the charge, in ounces, as follows:—

Lines of least resistance in feet.	Charge of powder. lbs.	oz.	Lines of least resistance in feet.	Charge of powder. lbs.	oz.
1	0	0½*	5	3	14½
2	0	4	6	6	12
3	0	13½	7	10	11½
4	2	0	8	16	0

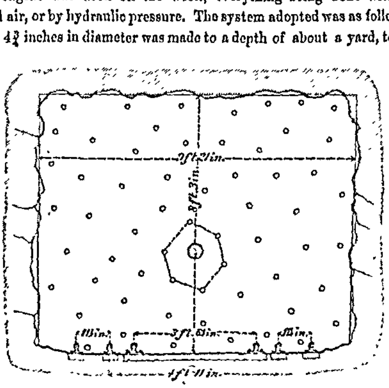
These quantities being of common merchants' blasting powder, will be found adequate for any rock of ordinary tenacity; but a precise datum

* To so small a quantity as ½ ounce a little excess might be added, but ¼ ounce or ½ ounce more will be sufficient.

should be ascertained by a few actual experiments on the particular rock to be worked; thus, with a 2-feet line of least resistance, (AB), whether 4 ounces, or 6 ounces, or 8 ounces are requisite to produce a good effect; with 3-feet line of least resistance, whether, 13½ ounces, or 18 ounces, or 27 ounces, &c. On the results of these trials a scale may be adopted for guide in the work.

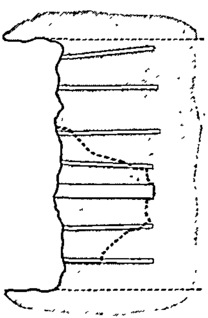


The accompanying sketches show an admirable method of arranging blast-holes, being illustrations of the mode adopted in blasting the Mont Cenis tunnel, the most recent and grand example of this form of Engineering. This tunnel, nearly 8 miles in length, occupied 12 years in construction, at a cost of about £224 per running yard. Not a single steam engine was used on the work, everything being done with compressed air, or by hydraulic pressure. The system adopted was as follows:— A hole 4¾ inches in diameter was made to a depth of about a yard, towards



CROSS SECTION OF THE ADVANCED GALLERY.

Fifty to sixty holes, according to circumstances, of less diameter, but of about equal depth, were then driven into the remainder of the face. All the holes were then dried, and cleaned by jets of compressed air, the "Affût" was withdrawn behind strong iron bound doors, and six of the small holes nearest to the large one were charged and fired. The force of the explosion went in the direction of least resistance, that was toward the centre hole, and a breach was made such as is indicated in the longitudinal section, by the thick dotted line. The remaining holes were then charged and fired in sets of six or eight at a time, those nearest to the breach being exploded first. This system was found more economical than firing a large number of shots at one time. The wagons were then advanced, and the dèbris was cleared away; the two pairs of rails at the sides shown in the cross section, were for wagonettes, whose contents were afterwards transferred to large wagons. The "Affût" was then again advanced. These operations were repeated with unvarying regularity twice every day.


LONGITUDINAL SECTION OF THE END OF THE ADVANCED GALLERY.

The "Affût" is a ponderous frame supporting nine of the machines known as "perforatrices," each perforatrice propelled a boring rod which struck the rock at the rate of 200 strokes per minute, with a force of 200 lbs. These perforatrices were driven by means of compressed air: the compressive force being obtained from the water of a *mountain stream near the mouth of the* tunnel. The working of a "perforatrice" is thus described by an eye witness.

"The perforatrice—a simple-looking cylinder fixed in a square frame, and connected with a few pipes and stop-cocks,—was placed in a fresh position in front of the rock, and at a sign from the engineer, was set in motion. A boring-rod darted out like a flash of lightning, went with a crash against a new part of the rock, chipped out several fragments at a blow, and withdrew as quickly as it had advanced. Bang, bang, it went again with the noise of a gong. In ten seconds the head of the borer had eaten itself a hole; in a minute it had all but disappeared, in twelve it had drilled a hole nearly a yard deep, as cleanly as a carpenter could in a piece of wood.

England existed as a nation ; old Bhur forts near showing marks of smaller wedge holes.

The rates now being paid for quarrying are—

	R.	A.	P.
For ashlar, 1 to 20 cubic feet, per foot, - -	0	2	0
„ 20 to 40 „ „ - - -	0	2	6
„ flags, 2 inches thick, - - -	0	3	0
Rough dressing the ashlar, - - -	0	1	0
For large rubble, per 100 cubic feet, - - -	3	14	0
„ small „ „ - - -	1	8	0

The ashlar is rough dressed before it is taken out of the quarry ; this has been found to save two-fifths of the carriage.

CHAPTER II.

BRICKS.

22. Bricks are made of tempered clay formed in a mould to the requisite size and shape, and then dried in the sun. In this condition they may be used for building, and are called sun-dried bricks, or in Hindoostanee, *kucha*. For most permanent works, the bricks are hardened by strong heat in a kiln, and when thus prepared are called burnt or kiln bricks; in this country, *pucka*. But on account of imperfections in the application and distribution of the heat in a kiln, it never happens that all the bricks put in are thoroughly fired to the required extent and no further. Some which have not received sufficient heat are only partially hardened, and such are, from their generally *yellowish* tinge, known as *peela* bricks. Some also may have received too much heat; when this happens, and especially if they contain a large proportion of sand, they are more or less vitrified, and when cool, are dark-colored, hard, and brittle. Such are also in general distorted, and when this over-burning has proceeded to a great extent, they are found partially fused and run together into masses, frequently of large size. These irregular lumps of over-burnt bricks are called *jháma*.

A sound and well-burnt brick is generally of a clear and uniform color, depending on the nature of the clay of which it is made, and partly also on the kind of fuel with which it has been burned. Bricks of a deep red color are generally good. A good test of hardness is that the finger nail should not be able to make any scratch or mark on the surface of the brick; and it should emit a clear ringing sound when struck. An imperfectly burned or *peela* brick possesses neither of these qualities. By its ready absorption of damp from the air, it is very liable to be affected by the action of saltpetre or other salts, which, on crystallizing, cause the brick to crumble away. It is incapable of withstanding continued exposure to the action of water; it softens and is liable to be crushed. A perfectly burned brick will remain any length of time under water uninjured, and this

quality is so essential in hydraulic works, that the absorbing power of the bricks employed should be carefully tested beforehand, and if it exceeds $\frac{1}{10}$th of the dry weight, the bricks should invariably be rejected.

23. Brick-earth.—The first part of the process of brick-making is the *preparation of the clay*. It should neither be very stiff and "fat," as it is called, nor very loose and sandy. If the former, the bricks are very liable to crack in drying, and are more likely to be imperfectly burned; if the latter, they are soft and fragile, and more apt to fuse in burning.

All clays burning red contain oxides of iron, and those having from 8 to 10 per cent. burn of a blue, or almost a black color. The bricks are exposed in the kilns to great heat, and when the body is a fire-clay, the iron unites with a portion of the silica, forming a fusible silicate of protoxide of iron, which melts into an external glaze. Bricks of this description are common in Staffordshire, and, when made with good machinery (that is, the clay being very finely ground), are superior to any others, particularly for docks, canal or river locks, railway-bridges and viaducts. In some places these blue bricks are commonly employed for paving purposes. Other clays contain lime and no iron; these burn white, and take less heat than any other to burn hard enough for the use of the builder, the lime acting as a flux on the silica. Many clays contain iron and lime; when the lime is in excess, the bricks are either of a light dun color, or white, in proportion to the quantity of that earth present; if magnesia is present, they have a brown color; and if iron is in excess, they burn from a pale red to the color of cast-iron, in proportion to the quantity of metal.

There are three classes of brick earths:—

1st. Plastic clay composed of alumina and silica, in different proportions, and containing a small percentage of other salts, as of iron, lime, soda, and magnesia.

2nd. Loams, or sandy clays.

3rd. Marls, of which there are also three kinds; clayey, sandy, and calcareous, according to the proportions of the earth of which they are composed, viz., alumina, silica and lime.

Alumina is the oxide of the metal aluminium, and it is this substance which gives tenacity or plasticity to the clay-earth, having a strong affinity for water. It is owing to excess of alumina, that many clays contract too much in drying, and often crack on exposure to wind or sun. By the

addition of sand, this clay would make a better article than we often see produced from it. Clays contain magnesia and other earthy matters, but these vary with the stratum or rock from which they are composed. It would be impossible to give the composition of these earths correctly, for none are exactly similar; but the following will give an idea of the proportions of the ingredients of a good brick earth—silica, three-fifths; alumina, one-fifth; iron, lime, magnesia, manganese, soda and potash forming the other one-fifth.

If any gravel is mixed with the clay, it must be carefully separated. It is, however, often so mixed, that before the clay is fit to be moulded into bricks, it should be subjected to the process of being passed between rollers and afterwards through the pug-mill; though if the former has done its work well, and effectually crushed the gravel,* the pug-mill need not be used except for the preparation of moulding, arch, and column bricks, and particularly for tile-making. The gravelly clay is generally of a yellow ochreish color, and the pebbles containing lime, would, if burnt with the clay, expand and split the bricks. Attention, however, is necessary in the use of this clay or marl containing lime, as but a very small proportion of that substance is admissible in brick clay, and then only in a pulverised state. The presence of lime can easily be tested by pouring a little acid on a solution of the clay, when, if it be present, an effervescence will be apparent. In alluvial soils, bricks made of the upper earth are apt to crack in drying, and warp in burning, however well tempered or mixed with other ingredients: such soil is therefore to be removed and better clay sought for below.

In India by far too little attention is paid to the preparation of brick-earth. The soil should be dug, and if not naturally fit for the purpose, ought to be artificially rendered so, by the following means:—Quantities of clay† each equal to the manufacture of about 2,000 bricks or 260 cubic feet, are to be dug up before the cold weather, (September and October,)‡ and laid on levelled ground, which, if a little below the general surface is better. If sand is required, it is then added; if not, the clay is worked

* This is the practice in Warwickshire, where the best bricks in England are made.

† Earth impregnated with *reh* (sulphate of soda), which abounds in the N. W. Provinces and the Punjab is wholly unfit for brick-making.

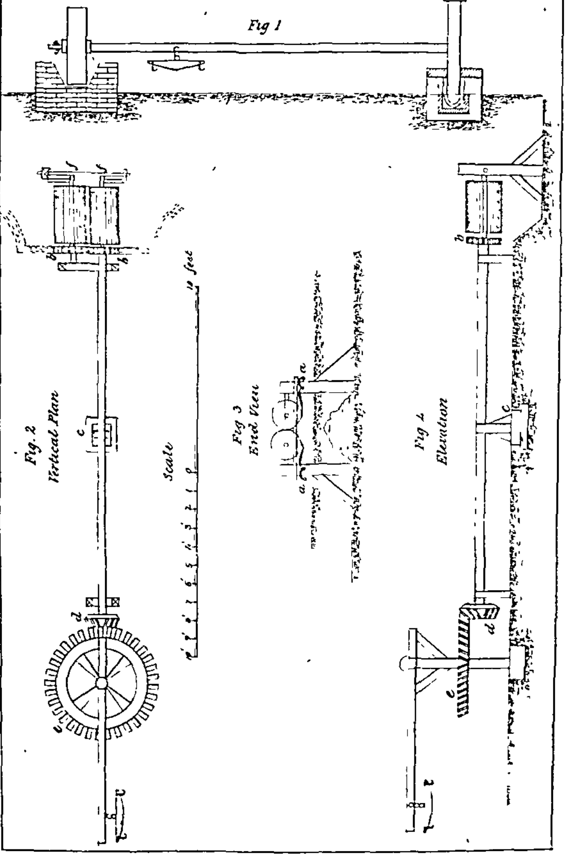
‡ It is generally known by the month of October, what work is likely to be undertaken during the following year, and the quantity of clay can be accordingly prepared, and sufficient bricks obtained to last till the succeeding year's kilns are burnt.

without; but in either case, it is subjected to a tempering process; being cut, slashed, and well worked with spades or *phaorahs*, adding water to soften it. If the clay is gravelly, it is to be passed between the rollers previous to being tempered. When the clay has been well worked for several days till no lumps are perceptible, it should be left till February, when, the sun getting warmer, the whole will have become an uniformly soft and yielding mass. This process should be considered necessary as well for sun-dried as for kiln-burnt bricks, and even for the clay plaster with which the former are almost always covered, to which a proportion of cow-dung should be added.

24. The *Clay-crushing Rollers*, may be of iron or very hard stone; their length is 3 feet and diameter 18 inches, laid horizontally and close together. The outer ends of the axles turn in brass channels, *f f* (see *Plate* I., *Figs.* 2, 3, 4,), with a slight inclination towards the centres, and are prevented from sliding when hard substances are being crushed, by preventive screws. On the inner ends of the axles at *b*, are toothed wheels of the same diameter as the cylinders, to communicate rotary motion from one axle to the other. The axle of one is prolonged by a shaft about 20 feet long, carrying at the extremity a bevelled wheel *d*, worked by a motive-wheel *c*, 6 feet diameter, the axle of which is raised to the height of a horse's shoulder or bullock's neck, to which an arm is fixed for cattle to be attached to. The motive-wheel is level with the cylinders, and the connecting shaft supported midway, as at *c*, in a block and brass box. Just below the rollers is a pit to receive the crushed clay, and scrapers are so suspended under the rollers, that their edges press against the surfaces of the cylinders, to scrape off all clay that adheres, which would otherwise clog the motion. Counter-weights *aa* are suspended in prolongation of the blades to keep the edges close to the cylinders.

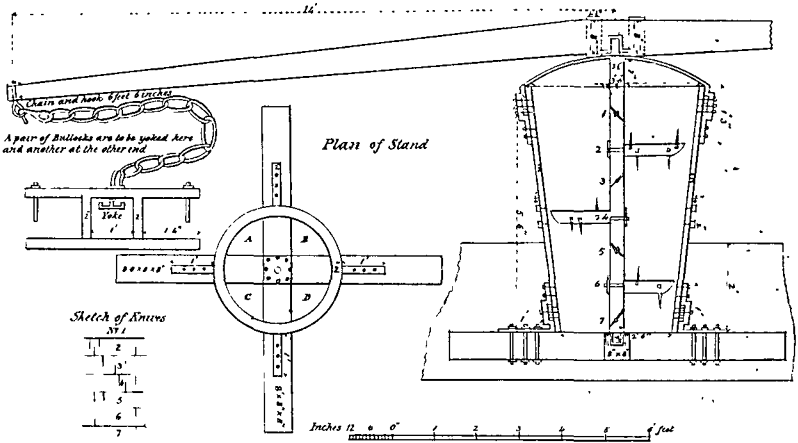
25. *Pug-mill.*—In *Plate* II., are given the plan and sections of a pug-mill for tempering clay for bricks. The clay is put in at top, and water is added as required to moisten it, the mill being kept constantly at work. It is turned by bullocks. There are six hoops on the tub, 2 inches wide and half an inch thick. The six top knives are 4 inches wide, and are bolted into the spindle, at an angle of 45 degrees, having teeth let into them: the blades of the teeth are 4 inches long, without the screw and nut which attaches them to the knives. The teeth are fastened to the knives at unequal intervals. The seventh, bottom, or shooting knife

CLAY-CRUSHING ROLLERS.



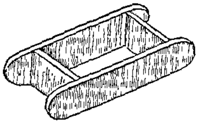
SECTION OF A PUG-MILL,

For preparing Clay for Brick making.



average under 100 lbs., though some lately weighed at Roorkee averaged 6 seers each, being 12 × 6 × 2½ inches, equivalent to 116 lbs. per cubic foot. The specific gravity of brick is 1·841; it absorbs $\frac{1}{16}$th of its weight of water; and is crushed by a force of 962 lbs. on the square inch, if perfectly well burnt.

28. Moulding.—The *Mould* for forming the bricks is $\frac{1}{12}$th to $\frac{1}{20}$th arger than the size of brick to be made, as the clay shrinks in burning. The size of mould formerly in use at Roorkee and in other parts of these Provinces, measures 13 × 6½ × 2¾ inches, and the average size of the pucka brick is 12 × 6 × 2½ inches. As however, the thickness of walls is generally calculated in even feet and half feet, the bricks ought to be somewhat less than a foot in length to allow for mortar joints, plaster, &c., and their breadth should be something less than half their length, in order that two *headers* with a mortar joint between them may cover a *stretcher* or the full length of a brick: a convenient size therefore is 11½ × 5½ × 2½ inches, which, with most brick soils, would require that the moulds should be 12½ × 6 × 2¾ inches. English sized bricks are, however, now generally coming into use in India.



The bricks in use on the East Indian Railway measure, for the most part, 9 × 4 × 2½ inches; the price of moulding ranges from 8 to 12 annas per thousand, according to the supply of labor. A native moulder, assisted by a boy to supply the clay, and a woman to remove the bricks, *can* make 1,200 (or more) bricks by an ordinary day's labor. Generally the moulder has one woman to take away the bricks as he makes them, and the average number he moulds a day rarely exceeds 500.

Brick moulds are made of any hard wood, which should be thoroughly seasoned, and the edges, which wear very fast, should be protected by a thin strip of iron. Moulds should be frequently gauged, especially when the brick-makers find their own moulds, or the bricks made will vary much in thickness. In England, brick moulds are now made lined with brass, which shows the importance attached to the correct moulding of bricks.

Two methods of moulding are known in England, *slop* and *sand* mould-

ing. In the former the mould is dipped in water every time it is used, in the latter, it is sprinkled with fine sand or with ashes from an old brick kiln. In either case the brick-earth should not be used too wet; and it should be pressed carefully and thoroughly, so as to fill the moulds. The superfluous earth is then removed by a *strike*, which is a straight edge of wood or metal passed along the top of the mould, and pressed well down on its edges. Steel strikes are best, as wooden ones are cut by the edge of the brick mould, and then scrape away too much of the surface of the brick, thereby rendering its thickness irregular.

In England, bricks are moulded on boards or benches; in India, mostly on the ground, which should be made as smooth and even as possible. At Roorkee, smooth plastered terraces have been used, the surface sprinkled with fine sand or ashes. The bricks are moulded side by side till the terrace is covered, they are then left on it, till dry enough to be turned on edge without loss of shape; then, after another short interval stacked; or, as it is called in England, laid in a *hack*.

At Roorkee a moulder makes generally from 800 to 1,000 bricks per diem. He *can* mould a larger number, but they are then apt to be less carefully made and inferior accordingly. The number of attendants on each moulder to supply clay, water, &c., will depend on the distance of the moulding ground from the place where the clay is dug, and both of these from the water. And this is a point requiring consideration before beginning to make bricks, as it is one which will materially affect their cost. The following is a detail of the usual monthly amount of labor required, with the expense of every four moulders, having eleven beldars to assist.

1 Moulder, at 6 Rs. per mensem, ...	6	0	0
2¾ Beldars, at 4 ditto, ...	11	0	0
Sundries, ...	1	0	0
Total Rs, ..	18	0	0

In one month of 26 working days, 1,000 bricks being moulded per diem, the total number will be 26,000, or deducting ten per cent for breakage, 23,400, costing Rs. 18; or Rs. 76-14-9 *per lakh*.

If the quantity made by each moulder is 800 only per diem, the total number will be 20,800, or, with deduction as above for loss, 18,720; the rate per lakh being Rs. 96-2-6.

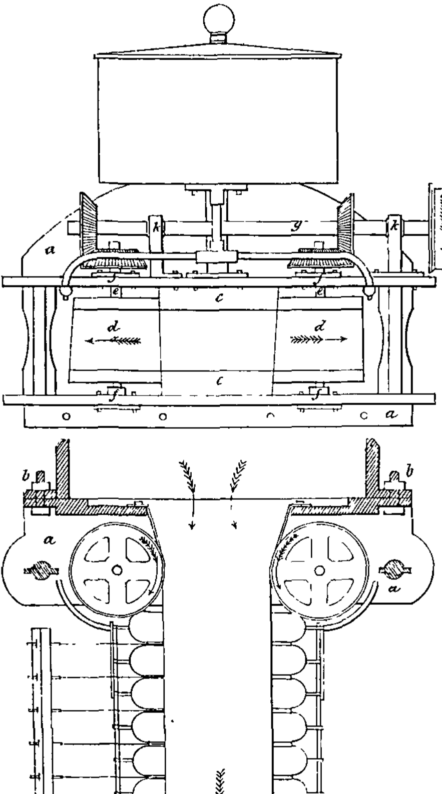
clay is thoroughly mixed and forced to the other end *b*, of the pug-mill, from which it is carried forward into the moulding chamber, or rectangular box C.

Third, in this box a reciprocating piston moved by a rack and pinion motion underneath, forces the clay alternately from either end through two roller dies, D, D, in a continuous rectangular bar; which is sufficient to produce from 8 to 12 bricks edgeways, the width of the clay being the length, and the thickness the width of the bricks required. If the piston be supposed to be moved towards one end of the moulding chamber, the hollow in the rear of the piston is supplied by the pug-mill shaft as fast as the piston advances; therefore, the whole time, the clay is under a uniform pressure, whereby very important objects affecting the quality of production have been secured, more especially in regard to size and density. When the piston reaches the end of the box, it is reversed, and commences to force the clay out of the other end; whilst this bar of clay is divided into bricks and carried away, each delivery giving just sufficient time to divide and clear the bricks, before commencing delivery again on that same side; so that the bricks, without loss of time, are turned out alternately during the day.

As the success of the machine depends greatly on the arrangement of the rotary dies D, D, they have been drawn to a large scale, *Plate* III. The following is a short explanation of the figures: *a*, *a*, *a*, is one casting, and is a frame and support to the whole; it is fixed to the end of the machine by bolts *b*, *b*, through holes in the back of *a*, *a*. The upper and lower sides *c*, *c*, of the orifice are made of brass, in order to stand as long as possible; two rollers *d*, *d*, covered with fustian cloth and bound with brass, form the other sides of the orifices, and are fixed vertically by the spindles *e*, *e*, being movable in the bushes *f*, *f*; these receive motion by bevel gearing from the horizontal shaft *g*, which is supported in the bearings *l*, *l*, and driven by a strap on the pulley *h*, keyed to the shaft *g*; the leather strap is connected to a convenient shaft of the machine. It will be seen that, on turning the pulley *h* in the direction of the arrow, the rollers will be turned in opposite directions, and thereby greatly assist the clay to leave the machine.

Above the die is a large water box, supported on a cast-iron standard; the water is brought by an iron pipe fixed in the bottom with a screwed end and backnut, and then branches right and left by a T piece to the

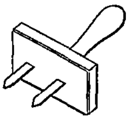
BRICK-MAKING BY MACHINERY.



outer edge of the rollers; at the ends of these branches, is a small brass cock, to regulate the supply of water, and to allow it to drip on the top edge of the rollers; this causes the clay to leave the rollers with a perfectly smooth face.

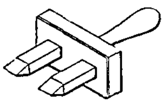
By referring to the section *Plate* III., the advantage of this roller arrangement is at once seen; the rollers *d*, *d*, not only avoid great friction, but compress the clay while it is being forced forward by the piston through the orifice, thereby producing a solid bar of clay with very clean arrises, which then moves forward in a horizontal position on a table or cutting frame, consisting of wooden rollers covered with similar cloth to the vertical rollers *d*, *d*, and with iron spindles, revolving by the friction of the clay as it advances. This bar of clay is the length and breadth of a brick edgeways. It will be noticed that the rollers *d*, *d*, are slightly tapered towards the top (in the drawing rather exaggerated); this is just sufficient to allow for the spreading of the clay on the bottom side passing along the rollers; the clay when drawn to the full length of the table, is ready to be cut into the required thickness for bricks; this is done in the following manner, while the machine is delivering a similar bar of clay on the opposite side. Between the rollers is a series of strained steel wires, fixed in a frame, movable on two centres underneath. By passing this frame smartly from one side to the other of the bar of clay, it is thereby cut into so many bricks the thickness required.

Fig. 1.



There are various ways of taking off the bricks; some use small leather pads fixed on the fingers by a small loup, presenting a smooth surface to the brick, or solid bricks are sometimes removed with a fork as shown in *Fig* 1, the two prongs being made of sheet iron and firmly fixed into the handle, these prongs are forced into the brick and then it is lifted off. In the case of hollow bricks, a fork is used with two or more wooden prongs, tapered at the ends as in *Fig*. 2, these are inserted in two of the perforations and the brick lifted off. The fork is used in the right hand, and a pallet board taken in the left, after the brick is raised, it is put against the pallet board and turned horizontally; then the fork is withdrawn and the brick left on the

Fig. 2.



pallet, when it is put on the wheel-barrow and taken away to the backing ground.

This machine is capable of turning out 30,000 bricks a day with proper attention, so that the bricks do not fall off the machine and became spoilt; 25,000 is the least average with a ten-horse power engine; *two smaller sizes*, worked by steam, horse or water power will turn out from 10 to 20,000. These machines will make solid or perforated bricks of any description, viz., cant, or splayed bricks for plinths; weathered, and throated copings of several sizes; round copings; ogee moulded, or quarter *round nosed bricks; wedge shaped for culverts; compass, or* curved bricks for lining shafts and wells; air bricks for ventilation; damp proof course to prevent damp rising in walls; drainage and gutter bricks for wash-houses; also paving, roofing, and drainage tiles of all descriptions. *Fig.* 3 shows how the cores are fixed for perforated bricks, *Fig.* 4 is a cross section of the core itself; these will be understood without explanation.

Fig. 3.

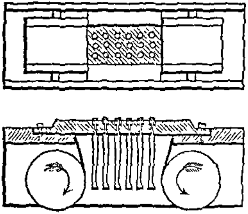


Fig. 4.

30. The tools and implements required for hand moulding bricks in India, besides those mentioned above, and the wear and tear of which form an item in the expense of brick-making, are a *Churus* or *Mōth*,* (large leather well buckets), and ropes for the same, &c; ro a Persian wheel, or *Dhenklee*,† or other apparatus for raising water. Also *Handees* or *Ghuras*, earthen vessels for carrying and holding water; *Phaorahs*; and bamboo hand-barrows, with leather shoulder straps for carrying earth.

* The *Moth*, is a churus with a *trunk*, which by means of a small rope attached to its extremity and passing over a second pulley at the edge of the well, is drawn up with the open end raised (which prevents the escape of the water), and reaching the top, is extended, discharging the water into the reservoir at the side, without the assistance of a man at the well mouth, which the *churus* requires.

† The *Dhenklee* consists of a bucket suspended by a rope to the extremity of a pole, balanced on a fulcrum very near the other extremity, by means of a load of stones, a mass of mud, or other counterpoise. A man holding the rope draws down the end of the pole till the vessel is plunged into the water and filled, when with the aid of the counterpoise, he easily rises it, and pours out its contents by turning it over when it has been brought to the level of the ground on which it stands. These machines are further described in Vol. II.

a light to a dark hue, the drying is complete, and the fire may be urged. The first, or white smoke, called water-smoke, is, in fact, little else but the steam of the water while evaporating, and when that is gone, the real smoke of the fuel succeeds. Now the vents may be opened to admit a full draught, and a strong fire kept up for from forty-eight to sixty hours; but the heat must not be white, or so strong as to melt or vitrify the bricks, and whenever it appears to be increasing too rapidly, the vent must be partly closed. By this time the kiln, if it contains thirty-five courses, will be found to have sunk about nine inches; but, the stronger the clay, the more it will shrink, and it is by this sinking that the workman knows when the kiln is sufficiently burnt. The experience of burning a few kilns will show how much the clay of that particular place yields to the firing. When it is thus ascertained that the kiln is ready, the vent-holes, and all *other chinks through which air can enter*, are carefully stopped with bricks and clay. In this state it remains until the bricks are cold enough to be taken down, when they are distributed for use.

From the nature of the above process it will be evident that bricks of very different qualities must be found in the same kiln; for, as the fire is all applied below, the lower bricks in its immediate vicinity will be burnt to great hardness, or, perhaps, vitrified; those in the middle will be well burnt; and those at the top, which are not only most distant from the fire, but more exposed to the open air, will be too little burned or *peela*; consequently, if they are to be used, they must be reserved for inside work that is not exposed to the weather, or they will soon fail and crumble to pieces.

34. Indian kilns.—The kiln walls may be built of kucha bricks plastered with mud, and repaired with the same material from time to time; they should slope on the outside about one foot in five, and be plastered with mud and *bhoosa*.

There are various methods *in practice in India of filling and firing* a kiln of the same construction as the above.

1st.—Laying alternate complete layers of wood fuel and of bricks, the flues passing only 5 or 6 feet into the interior of the kiln, all the rest of the *floor being occupied by the first layer of fuel.*

2nd.—Arranging the bricks in a second set of flues five or six courses above the first, and crossing them at right angles; and so on with flues alternately in these two different directions to the top: or

3rd.—Having as before, one series of flues at bottom, and above, alternate complete layers of bricks and fuel.

35. *Mahewah Brick-field.*—The following account of the working of the brick-field at Mahewah, near Roorkee, where operations were (in 1867) carried on in the English style, will be further illustrative of the foregoing paragraphs, and supply more detailed information. The details are illustrated in *Plate* IV.

The *Earth*, for making the bricks, is prepared from the spoil bank of an old cutting; down the middle of this bank a deep trench has been dug, which fills with water in the rains, and is supposed partially to temper the clay.

The *Pug-mill* [*Fig.* 1] is sunk 2¾ feet, so that the clay may be tilted in, by an easy ramp leading to the top, and at the same time the men below may be able to lift the prepared clay to the level of the ground. The casing of the mill is made of ¼-inch sheet-iron, 4 feet high, and 3 feet diameter at top and bottom. The casing is raised 12 inches from the bottom of the pit, and half the mill is bricked up; the clay oozing out of the opening thus formed on the unbricked side. The shaft is made of 2½ inch square bar iron, having 7 iron blades, 4 inches × ¼ inch, and supported at the top on three sides by T iron struts, the fourth being open to leave room for tilting in the earth. The uppermost blade is 1¼ feet from top of iron sheeting, and inclined at about 25°, the angle increasing with each blade, the lowest one being 70°. The lever is 15 feet long, and worked by a pair of bullocks. This mill is sufficient to supply six tables.

The *Moulding tables* are 6½ × 2¾ × 2½ feet; to each is fixed the lower part of the mould, [*Fig* 2], and an iron basin holding water in which the wooden strike is kept. The *strike* should be made of deodar or some fir wood, and a new one issued daily to each table. At right angles to the table and to the left of the mould is the *page*, [*Fig.* 3], consisting of two parallel ¾-inch rod iron bars about 7 inches apart, bolted at one extremity to the frame of the table, and at the other to an upright plank, and supported at the centre by another upright plank. Under the table is a strut, immediately below the centre of the mould, to prevent any "kick" or spring from the table. This should be looked to and be wedged up every day.

The *Brick mould* [*Fig.* 4] is of $\frac{3}{16}$-inch iron, 10 × 4⅞ × 3½ inches, inside measurements; when put on the table it rests on the four adjusting screws A, A, &c., [*Fig.* 2], which are so regulated that the bricks turned out are the required thickness, 3¼ inches. The tops of these screws, as also the parts where the mould rests, become indented from the constant blows on them and might, with advantage, be steeled. The bottom of the mould, which is also iron, has a die upon it, 8 × 2½ inches, raised ⅛-inch, *this makes an indentation in the brick which is intended to hold the* mortar, and enables the mason in building to draw the joints very fine. To mark the brick, the letters G. C (Ganges Canal) are raised ⅛-inch on the die A wet brick, as turned out of the mould, weighed 4 seers 12 chittacks; when sun-dried, 3 seers 12 chittacks.

Moulding and Stacking.—The man who prepares the clay into suitable lumps for the moulder, must be careful to make each lump solid, without cracks, by repeatedly thumping and pressing it on the table, as these cracks form blemishes in the moulded brick. At the same time he must be careful in keeping his part of the table well sanded.

The mould is cleaned first with water and then sanded, the die being cleaned when necessary with a country made horse-brush. The moulder takes one of these prepared lumps in both hands and, raising it above his head, throws it into the mould; he then clears off the superfluous clay with his hand (taking care to leave the full amount required) and pressing the remainder into the mould, strikes it with a small wooden straight edge; the strike is cleaned, as it is put back into the water, against the sharp edge of the iron bowl.

Having moulded the brick, he places the mould sideways, with a smart blow, on the bars of the page, which, by their spring shake the brick loose; he then places a board 12 × 6 × ½ inches against the lower side of the mould, and putting the board flat on the bars of the page, with the brick and mould resting on it, removes the mould, and slips the board, with brick upon it, along the bars of the page to make room for the next.

The bricks are sanded and carried away on the boards in hack-barrows (*Fig.* 5), which hold 26, (viz., 13 on each side). The hacks are on terraces, raised 9 inches from the ground, and covered with a layer of flat bricks laid dry; they are three bricks broad, so as to hold two rows, and long enough to hold the day's work of a moulder, as putting on a second course the same day spoils the shape of the bricks. A moulder can make 1,000 bricks per day; and when working by contract, 1,500.

In hacking the bricks, they are lifted from the hack-barrow between two pallets, viz., the original one below the brick and another put on the top; by this means the shape of the brick is not injured; they are placed at once on edge, with the distance equal to the thickness of a pallet between them, and each brick breaking joint with the one below; the top of each row must be sanded before the next is put on.

The number of hands employed at six tables are :—

3 men to dig, prepare earth and pump water.
3 „ to wheel prepared earth into the pug-mill.
2 „ to take the earth as it comes out of the pug-mill and place it in lumps on the level of the ground.
2 „ to carry the lumps from pug-mill to moulding tables
6 „ (one standing opposite each moulder) to prepare the earth in suitable and compact lumps for moulder.
6 „ moulders.
6 „ (one to each table) to carry the bricks away and hack them.
One pair of bullocks to work pug-mill.
2 boys to turn the bricks on their backs while drying.

Total, $\left\{\begin{array}{l}\text{28 men,}\\ \text{2 boys,}\end{array}\right\}$ and one pair of bullocks.

The moulders are paid Rs 6 per mensem, the other laborers from 4 to 5; boys, from Rs. 2 to 3.

Kilns.—The floors of the kilns are level with the ground, the flues and ash-pit are sunk 4 feet. The flues face N. and S., that is, at right angles to the direction of the prevailing wind.

The fuel is thrown on to the iron bars of the flues through an iron door [*Fig.* 6], which must be always kept shut, except when supplying the fuel, as an immense amount of heat is lost if it be left open; and this the stokers are very apt to do, unless closely watched, as the doors are difficult to open By putting an iron ring on the door instead of the knob handle, as at present, and opening with a detached hook, this difficulty might be obviated.

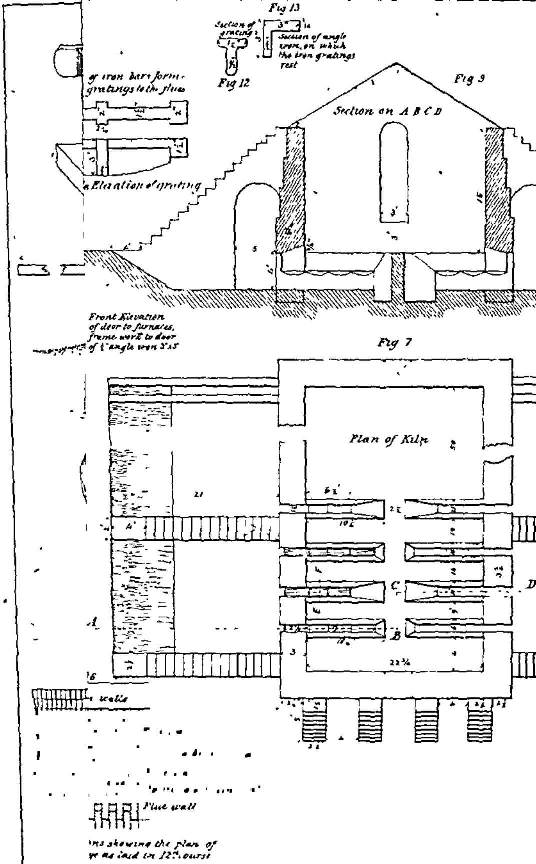


Fig 13
Section of grating
Section of angle iron, on which the iron gratings rest
Fig 12
Fig 9
Section on A B C D
of iron bars forming gratings to the flues
Elevation of grating
Front Elevation of door to furnaces, frame work to door of angle iron
Fig 7
Plan of Kiln
A
B
C
D
walls
Flue wall
showing the plan of as laid in 12th course

The sill of the doors is raised 6 inches above the top of the grating.

There are two sizes of kilns in use at Mahewah. *Figs* 6, 7, 8, 9, 10, 11, 12, and 13, give all the dimensions of the larger size as built at present; but only one or two kilns of this size have as yet been fired. From the experience gained in burning these it is proposed to make the following alterations in the next ones built.

The two flying buttresses on each side will be removed, as they make the stock-hole so hot towards the end of the burning that the stokers can hardly remain there, at the same time the walls, which are at present too thin, are to be made 4 feet 6 inches at bottom and 3 feet at top, and buttresses left only at the four corners. The flues are to have only three sets of bars each (with 9 bars in each set), the remainder of the flue being sloped up (shown in every second one, *Fig.* 7), as with four sets of bars the flue is too long to stoke properly.

This kiln holds 165,000 bricks. The walls are built of peela bricks set in mud and well "leeped," both inside and out. The kilns now burning are converted from Sindh kilns, which were already standing, and several dimensions had to be adapted to circumstances; one chief point being that the end flues are put too far in from the side walls.

The small kiln, built on Mr. Hickmott's* plan (measuring 30 × 18 feet, and 14 feet [illegible] thick [illegible] be a [illegible] heat. There are only four flues, 5½ feet apart, the two end ones being 2¾ feet from the side walls. Below the door of the flue is an iron damper to regulate the draft; it has been found *that when these are shut, the heat becomes so great in the flues that the bars of the grating* are bent and rendered useless, and the arch bricks fuse; they have therefore been discontinued in the new kilns The same effect is produced if the ashes are allowed to accumulate in the ash-pit, which must be kept constantly raked out.

This kiln holds 65,000 bricks.

The price of the iron-work at the Roorkee Workshops is as follows —

- 1 Fire-door, at Rs. 15 each.
- 1 Fire bar, 7 seers 6 chittacks, at Rs. 9 a maund.
- 1 Angle iron support, 12 seers 8 chittacks, at Rs 9 a maund
- 1 Iron brick mould, at Rs. 1-8 each.
- 1 Table complete (including table, die for brick mould and page), at Rs. 102.
- 1 Pug-mill (iron work), at Rs. 175.
- 1 Hack barrow, at Rs. 28.
- 1 Earth barrow, at Rs. 12.

In *loading the kiln*, the bricks for the first 11 courses are laid on edge close together in parallel walls (*Fig* 14,) with 5 inches interval between each wall, and 5 inches between the inside long wall of kiln and the first wall of bricks Where these parallel walls cross the flues, the bricks are corbelled out (*Fig.* 15), meeting in the 11th course. As it is most important that these openings should be properly built (as their falling in smothers the fires and causes every conceivable damage), a triangular wooden centering is used to insure regularity and proper bond. Another important point is that, the parallel walls should be built perfectly plumb and straight, as any unequal pressure coming on them when the bricks are soft from the intense heat, causes the wall to

* In charge of the large Government *Brick-yard*, at Akra, near Calcutta.

give in that direction, and the bricks above of course fall in. The centre wall is one or two bricks thick (according to the room left) with no opening for flues; the bricks, however, are placed on edge not quite touching, so that the communication between the sets of flues on each side is not entirely cut off.

In the 12th course (*Fig.* 16) the bricks are laid on edge, on the parallel walls, with the interval of a brick, between each, and the openings between the walls are bridged over by bricks on edge, alternating with those on the wall.

The 13th course is laid on edge, at an angle of 45° to the walls of the kiln, with the interval of about an inch between each brick.

The 14th course is laid on edge, parallel to the side of the kiln, leaving intervals of 1 inch; the upper courses are built each at right angles to the one below, the intervals getting smaller, till the last 5 courses, in which the bricks are placed close together, and a top course of bricks laid flat; over all this is put two layers of *oopla.*

If, whilst loading, there is any chance of rain, light king-post trusses, made of angle iron, are thrown across the top of the kiln; these are connected together by stout ropes and bamboos, and small choppas (12 × 10 feet) are placed on them.

Soft woods and dák (which is generally more or less decayed) are a bad description for burning, as they smoulder and do not give a brisk fire; of keekur, sissoo, or any hard wood, less than three-fourths the quantity, as compared with the soft wood, is required.

In *firing the kiln*, the arrangements are as follows:—

Commence firing in the evening with chips, just enough to warm the kiln (1 man to 3 doors). On the second evening, this small fire should be pushed back to the end of the flues. Third evening, the fire (still kept very low) is brought to the front again. Fourth evening, the firing is forced on vigorously; 2 men are now put on to every 3 doors, and the firemen are relieved every 12 hours. During the night, go to the top of the kiln, and should the fire be breaking out at any place, it must be immediately stifled by throwing a few baskets of ashes over the place where it is doing so. This must also be done on the next two nights, as that is the only time you can see how the kiln is burning.

The fires are kept up as strong as they can be till all the wood is burnt; the quantity, under ordinary circumstances for the small kiln, being about 10,000 cubic feet or 2,000 maunds of dák wood, or three-fourths of the same weight of sissoo, keekur, babool, or any hard wood; taking the latter at 4 cubic feet to the maund. This, if fired properly, will take 3 days and 3 nights of slow, and 3 days and 3 nights of vigorous, firing. When the kiln is burnt, it looks at night from the top like a molten mass, and appears almost transparent.

When the firing is stopped, the top of the kiln should be covered at once with 6 inches of ashes. The doors are left ajar for 12 hours, after which they are opened, and the whole of the openings carefully bricked up.

In the first kiln burnt, the openings were bricked up at once, and the bars and supports of the grating were found doubled up and rendered useless; whereas four kilns have now been closed in the manner recommended, and the grating bars are still good.

The kiln should on no consideration be opened under 15 days, and the longer they are left, of course the better the bricks will anneal.

The average weight of 4 pucka bricks after exposure to the cold weather rains was 3 seers $10\frac{1}{2}$ chittacks each; and after soaking for 24 hours in water, 3 seers $14\frac{3}{8}$ chittacks; average of absorption, 4 chittacks, or little more than $\frac{1}{15}$ of its weight. The

bricks were then placed in the sun, tilted up on a zinc roof for seven perfectly dry and cloudless days in April, and it was found that their weight averaged exactly the same 3 seers 10¾ chittacks, showing that they had not absorbed more than a normal amount of moisture at the time of first weighing.

Another pucka brick straight from the kiln, weighed 3 seers 9¾ chittacks; after soaking it in water for 15 minutes, it weighed 4 seers (all bubbling having ceased after about 13 minutes) After 6 days' immersion, it weighed 4 seers 0¾ chittacks, showing that a brick has absorbed nearly all the water it is capable of doing as soon as it ceases to give off bubbles, and that a quarter of an hour is ample time for soaking bricks before using. On soaking pucka bricks straight from the kiln, they absorbed on an average 6¼ chittacks; while those which had been exposed to the weather absorbed only 4 chittacks of water, showing that these bricks naturally absorb about 2¼ chittacks from the atmosphere in ordinary weather.

Out-turn.—As these are the first kilns of the kind that have been burnt at Mahewah, the results must be considered only as experimental:—

RETURNS OF SMALL KILN AT MAHEWAH.

Number of firing.	1st class brick	2nd class brick.	Half brick	Peela	Jhama brick.	Pucka roora.	Roora for soorkee	No of maunds of wood.	Description of wood.
						c. ft.	c. ft.	mds.	
1	21,600	11,000	...	13,000	3,330	300	200	950	Sissoo and babool
2	13,200	12,000	500	28,860	...	500	44	1,200	Dak.
3*	4,500	7,000	...	55,000	...	..	100	1,400	"
4	45,800	8,500	...	5,400	2,700	...	...	2,500	"
				LARGE KILN.					
	92,000	2,800	...	36,000	8,000	60	...	...	

There is no doubt when these kilns are once fairly started, that the out-turn will be far in excess of that here given.

Cost.—The bricks turned out from these kilns are of excellent quality, being well burnt and well shaped. It is impossible to estimate their exact cost without further experience; but the following, taken from the data above given, may be considered an approximation; though, doubtless, the cost will be reduced when the brick-yard is in full working order.

Approximate Estimate of the cost of a small Hickmott's kiln, to hold 65,000 bricks.

c ft.		Rs.
7,900	Peela brick in mud, at Rs. 5 per 100 cubic feet, ...	395
6,400	Excavation, at Rs 2-8 per 1,000 cubic feet, ...	16

* This kiln spoiled by rain.

No. c ft.		RS.
8	Iron doors, at Rs. 15 each, ...	120
32	Angle-iron rests, 10 maunds, at Rs. 9 a maund, ...	90
216	Grating bars, 40 maunds, at Rs 9 a maund, ...	360
	Total Rupees, ..	981
	Contingencies, at Rs. 5 per cent., ..	49
	Grand Total, Rupees, ..	1,030

Moulding.

6	Moulders, at Rs. 6, ...	36	per month.
15	Men, at Rs. 5, ...	75	
7	„ „ 4, ...	28	
2	Boys, at Rs. 3, ...	6	
2	Bullocks, at Rs 15, ...	15	
		160 = cost of moulding	

156,000 bricks, *i. e.*, 1,000 bricks per moulder per day of 26 working days—or about 1 rupee per 1,000.

Approximate cost of one kiln of bricks.

	R.	A	P.
Moulding 65,000 bricks, ...	66	0	0
$\frac{1}{10}$ cost of kiln for each burning, ...	103	0	0
Loading and unloading kiln, ...	15	0	0
2,500 maunds of wood, at Rs. 12 per 100 maunds, ...	300	0	0
Wages of firemen, ...	9	0	0
Plant, supervision, &c., ...	50	0	0
Total Rs., ..	543	0	0

Taking No. 4, or the last firing (in table of results), as the least out-turn that may fairly be expected from the small kiln (the other three being experimental only), and 2nd class bricks, as equal to half, and peela and jhama to one-fifth the value of 1st class bricks, then the whole out-turn will be equal in value to $45{,}800 + \frac{8{,}500}{2} + \frac{5{,}400 + 2{,}700}{5} = 51{,}760$ first class bricks.

Hence the approximate cost of the bricks may be put down as—

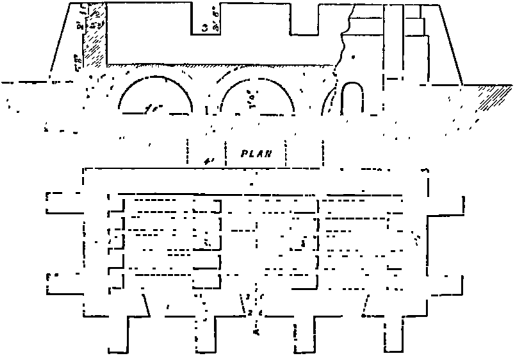
10·5 rupees per 1,000 for 1st class bricks.
5·25 „ 2nd „
2·1 „ peela and jhama.

Cost of Bricks.—The cost of bricks at a brickfield lately working between Roorkee and Saharunpore is at follows:—The bricks being $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ inches, well-shaped, and of excellent quality—the clay being dug and tempered on the spot without a pug-mill—the kilns of the same kind as those described in the text, at Mahewah—Moulding and stacking, Rs. 130 per lakh; Loading kiln, Re. 0-5-0 per 1000; Unloading, Re. 0-5-0 per 1000; Labor for burning, Rs. 35 per lakh; Wood, Rs. 16 per 100

maunds; 4,250 maunds being burnt per lakh of bricks. Each kiln holds 11,000 bricks, of which 8,000 are *pucka* and the rest *peela*. Cost of making a kiln, Rs. 150.

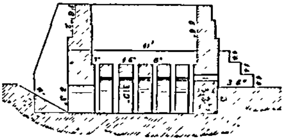
It burns four days and nights.—cools in eight days and nights—loads in five days—unloads in five days.

36. Sindh or Flame Kiln.—Another kind of kiln, which has long



been in great favor at Roorkee and elsewhere, (having produced very satisfactory results, especially where time was an object, but being perhaps inferior in an economical point of view to the English form of kiln above described,) is known by the name of the *Sindh Kiln*, having

SECTION ON AB



been introduced from that country into these Provinces by Capt. J. H

Weller, B E., whose experience of its successful working at Hyderabad in Sindh, has been made profitably available in many quarters. The kiln in use at Roorkee, is in some of its details slightly modified from that first constructed here under Captain Weller's personal direction.

Its interior dimensions are 31 feet 6 inches, by 11 feet, and height 6 feet 6 inches, above the flues. In the interior of the kiln, is a series of parallel walls running from end to end, 6 inches apart, and in height 4 or 5 feet. Three lines of arched openings in these walls, form the flues passing from side to side of the kiln, open on one side for the supply of fuel, and at the other having small draft openings (which latter have not been found at Roorkee to be of much use).

The floor is sunk 3 feet below the level of the ground, and access to the mouths of the flues is given by sloping away the ground on that side of the kiln, down to the level of the floor.

The whole interior of the kiln above the parallel walls is filled with bricks, at first with small intervals, and above packed close. No ashes are spread on the top, or covering of any sort. A vigorous fire is kept up by continued fresh supplies of fuel for forty-eight hours, and the kiln is then allowed to cool.

In this system, the loss by breakage is trifling, and the heat being very equably diffused, the return of well burned bricks is more satisfactory than in any of the other systems that have been tried.

A kiln of the dimensions noted above, contains 15,500 bricks of the usual Roorkee size, (12 × 6 × 2½ inches,) and the average proportion of *pucka* is 81 to 82 per cent.; some kilns have yielded a return of 9·28 per cent.

The consumption of dry wood is about 575 maunds for each kiln fired forty-eight hours. The flues should be roomy, and before lighting, should be filled up with the largest and most awkward shaped logs of firewood. These heavy pieces cannot easily be got into the fires after they are lighted, and have the advantage of giving a steady, and at the same time not too violent, heat for the first few hours; this is necessary, in order to dry the bricks gradually. If too intense a heat is applied suddenly at first, it is liable to "run" the bottom courses and arches, thereby stopping the draught and leaving the upper courses quite unburnt. When the bricks are dry, which will be after (about) twelve hours, according to the season, and may be ascertained by the cessation of white vapour passing

from the top of the kiln, the fires may be increased till the bricks are as nearly white hot at the top as they can be made. The two upper courses can never be made quite white hot.

The kiln will be burnt in a period varying with the strength and direction of the wind, the quality of the wood, and above all, with the amount of attention and labor bestowed on the firing. The least irregularity in firing is fatal; the arches from getting cold, and then suddenly hot again, are almost sure to fall before the burning is completed, and even if they do not, the bricks in the kiln are sure to be "shuffs." If the wood is stacked pretty near the kilns (say 150 feet off), five or six men for each fire will be necessary. Thus for a kiln with ten flues, fifty men (at least) should be allowed, and divided into a night and a day-gang, with at least one peon to each side of the kiln to look after them.

During the hot winds, it is very necessary to build a thin wall of kucha bricks to windward, to act as a screen, as without it all the fire goes to leeward, and the bricks to windward are all *peela*, while those to leeward, are *jummaed*.

Dry babool wood (*Acacia arabica*) of about four to six inches thick, and as long and straight as can conveniently be obtained, is the best fuel in the North-West Provinces; but, unfortunately, it is much more scarce and expensive than dhák (*Butea frondosa*), which accordingly is generally used.

All wood for fuel, but most especially dhák, should be allowed to get well dry before being used. Dhák loses at least 25 per cent. in weight in three or four months from the time it is cut

When the firing of the kiln is completed, a covering of dry earth, not less than four inches deep, should be thrown all over the top of the kiln, the flue openings built up *carefully* with kucha bricks and mud, and the bricks left to *anneal*. A kiln of the size mentioned above will require to stand sixteen or twenty days before being touched, care being taken all the time that none of the walls topping the flues fall down. After, say eighteen days, the flues to leeward may be opened, and next day those to windward; after two days more, the earth may be taken off the top, the openings for filling and taking out cleared, and the bricks removed.

37. The cost of bricks at Roorkee burned in this kind of kiln was Rs. 750 per lakh. Kilns therefore were used only because the demand for bricks was greater than could be supplied by Hindoostanee *pajáwahs* (or clamps, to be described presently), the number of which is limited by

the quantity of litter and *copla* produced in the neighbouring villages.

Extract from Report by Lieut. O. Span, Deputy Superintendent, Ganges Canal.

Memorandum showing the details of cost in the manufacture of 320,000 bricks.

The bricks are 13 × 6½ × 3¼ inches

The kiln is in every respect the Roorkee "Sindh kiln" pattern, viz, 31½ × 11 × 6½ interior dimensions, and having three sets of arches. The material for its construction has always been kucha bricks, and the arches peela bricks with mud cement.

The number of kilns burnt has been 23, and the average quantity of wood consumed 549 maunds.

The out-turn for the season gives exactly a rate of Rs. 700 per lakh, and 94 per cent. of pucka bricks.

The wood used has been exclusively *dhák* in a very dry state. I found a proportion of 50 maunds per kiln of almost green wood very useful for regulating the fire; in no case has the fire been fed beyond the specified 48 hours.

On closing the mouth, the top of the kiln has been invariably covered with a coating of 8 inches of ashes. The bricks are seldom cool enough to unload, until the seventh day.

The annexed memorandum shows the exact amount of expenditure for the season. It will be readily understood, that had all the bricks been made at the same place, the rate per lakh would have been very sensibly less. In this has also been included the cost of the materials used in the construction of bricks to be burnt, as well as the construction itself.

ACTUAL COST.

	RS.	A.	P.
Wood, per lakh of bricks, ...	362	8	0
Bricks, do., ...	123	0	0
Loading, do., ...	16	0	0
Unloading, do, ...	16	8	0
Firing, do, ...	21	0	0
Repairs to arches, do, ...	24	0	0
Sundries, do, ...	11	8	0
Making kiln, do, ...	90	0	0
Establishment, do, ...	32	0	0
Total, ...	696	8	0

This is of course exclusive of carting.

Under "bricks" is included the cost of moulding bricks, for the actual construction of eight kilns. The usual rate is Rs. 75 per lakh.

Repairs to arches are rather a heavy item which could, however, be very easily kept down, by having a set of wooden centerings; unfortunately I had not.

Making kiln, is here a very heavy item; it would have equally served 30 lakhs instead of 3 only

The more extensive the brick-making, the less the rate, inasmuch as a few kilns would burn any number of bricks; an item that runs the rate up where the localities are numerous, and would be still more so if a separate establishment was required for each.

The proper regulation of the fire is the great secret in burning; it should be kept at an uniform heat throughout if possible, and any carelessness at the close of the firing endangers the kiln; and excess of fuel at this state will assuredly cause the two bottom layers to vitrify.

The relays of firemen should be insisted on. Many, through avarice, attempt to carry on beyond their strength, and consequently the fire is but feebly fed. Each watch should be of four hours duration, certainly not longer.

The pokers should be of strong, straight, and green babool.

I think it very immaterial which way the kilns face, as I have built them looking to every point; perhaps it would however be as well to avoid the west, especially if brick-burning is to be continued in the hot weather.

In flame kilns especially, the bricks must be thoroughly dry before being loaded, or the great pressure will otherwise entirely destroy the bottom layers.

Wood to be in lengths of six feet, and as much as a man can conveniently get in, but certainly smaller than one's leg.

38. *Akra Flame Kilns.* Bricks are burned at Akra, near Calcutta, not only in *Clamps* with coal but also with wood in *Kilns.*

The flame kiln, or, as it is called in some parts of England, close kiln, is of great importance when bricks have to be burnt with wood fuel, when it would be difficult to produce good bricks from the process of "clamping" with wood, in a similar manner to the coal clamping system.

The size of the kiln can be varied to suit the wants of the locality. The width between each furnace is 4 to 6 feet, which may seem unusually large to those who know something about a flame kiln, but with wood it answers well, and has been used at Akra for brick and tile-burning for three years. The usual distance is, or used to be, 2 feet 6 inches; extending it to 6 feet admits of a saving in labor for burning, of more than half, besides the advantage of having only half the number of men engaged in so difficult and skilful an operation.

The wind is found at Akra to affect very much the firing. The kiln should be built to get the prevailing winds on both sides. If this cannot be done, a wall should be built to screen the fires from the action of the wind, or at least to break its force as much as possible at front or back.

The quantity of mango wood required to burn one lakh of bricks in a flame kiln holding that number, is 8,000 cubic feet, weighing 2,000 maunds. The quantity of soondry firewood is 4,000 cubic feet, weighing 2,000 maunds.

39. English Clamp.—In the English method of *open clamp* burning, without any kiln, the piling and disposition of the bricks is the same as that already described, (para. 32), except that the bottom arches are much small-

er, as they are only intended to contain brushwood to produce the first kindling, and not for the future supply of fuel. No fuel is used except the *breeze* cinders and small coal, and this is distributed, by means of a sieve, with wires about half an inch apart, over every course, as it is laid near the bottom, and over every alternate course, or every third course higher up in the clamp. The first layers of this fuel are from an inch to an inch and a half in thickness; but they diminish as they ascend, because the action of the heat is to ascend, consequently there is not the same necessity for fuel in the upper, as in the lower part of the clamp. The brushwood in the bottom ignites the lower stratum of fuel, and from the nature of its distribution, the vertical as well as horizontal joints will be filled with it, and thus the fire gradually spreads itself upwards, and the whole clamp is nothing but a mass of bricks and burning fuel. The heat is therefore, much more generally distributed throughout the whole mass; and in order to confine it, the entire outside of the clamp is thickly plastered with wet clay and sand, the bottom holes being opened or shut as occasion may require for regulating the draught of air.

Notwithstanding the heat is much more equably distributed throughout this form of kiln, yet the outside bricks all around receive very little advantage from the fire, and are never burnt; but being on the outside, they are easily removed, and are reserved for the outside casing of the next clamp that may be built; and being then turned with their unbaked sides inwards, some of them become available. On taking down the clamp, the bricks are assorted into three separate parcels or varieties, according to their perfection and goodness. Those that are burnt very hard and have not lost their figure or shape, may be selected for arches. The main body of well burnt bricks are called *stocks*, and those which are imperfectly burnt are called *place* bricks.

These several varieties of brick have each a separate price, the best being worth twice as much as the worst. If the fire has not been carefully attended to, and has been permitted to get too violent, some of the lower bricks will become distorted by partial fusion, and may fuse and adhere together, when they are called *clinkers*, and are useless for building purposes, but form an excellent road material.

A coal clamp of 100,000 bricks rarely burns out under a month. There is a great saving of fuel in burning large clamps, but where time is an object, small clamps ought to be made. The bricks ought not to

be opened out before they are thoroughly cool, and they are apt to crack by the breeze playing upon them when hot. The amount of coal to be used depends upon the quality of the fuel, and the degree of hardness to which it is wished to burn the bricks. 650 or 700 maunds of moderately *good coal ought to be sufficient to burn 100,000 bricks; a great deal,* however, depends also upon the clay; a light sandy clay, such as is found by river sides, takes less fuel than a hard, strong clay.

In London close (instead of open) clamps are employed, no spaces being left between the bricks. Each brick contains in itself the fuel necessary for its vitrification; the breeze or cinders serving only to ignite the lower tiers of bricks, from which the heat gradually spreads over the whole clamps.

40. Indian Clamp or Pajawah. The *pajáwah* is an arrangement for brick-burning in the open air, somewhat resembling the English *clamp.* The bricks and fuel are laid alternately, the former in courses of four

or five bricks, the latter of 2 or $2\frac{1}{2}$ feet in thickness, the proportion of fuel being diminished towards the top. The whole is generally built with one *side abrupt, and nearly vertical, and with a long slope on the* other. The fuel generally consists of dry grass, wooden chips, *khát* (manure), *koorah* (litter, miscellaneous dry sweepings) and *oopla* (dried cow dung), and very generally a layer of wood under all.

The form of the pajáwah is generally triangular; its floor smooth, and sloping at an angle of 15°, being lowest at the angle where it is lighted. The upper surface slopes at an angle of about 30°, in the direction of its length.

The following is a note on brick-burning in pajáwahs, by Lieut. J. Finn, formerly Executive Officer of Materials at Roorkee.

The quantity of fuel (koorah and oopla) used in the Hindoostanee clamps at and near Roorkee, *is about 6 inches thicker than the layer of kutcha bricks placed over*

it; that is to say, if the fuel is 3 feet in thickness, the layer of bricks placed on the top of it should be 2½ feet, or 5 bricks high; each brick being 6 inches wide. A clamp now being filled at Roorkee has a layer of wood about one foot deep all along the bottom, but none in the second or third tiers, excepting a small quantity at the mouth of the clamp to ensure its speedy ignition. When the clamp is ready for firing, about one foot in thickness of fuel (koorah only) is spread all over its top, and over that, one foot of ashes.

The undermentioned quantity of fuel will burn one lakh of bricks in a native clamp, viz.:—

325 2-bullock cart loads of khât.
750 Maunds of oopla.
100 Maunds of fire-wood.

Once a clamp is filled, covered over on the top with ashes, and fired, it is not liable to injury from high strong wind; nor will a heavy fall of rain harm a clamp when in the above-mentioned state.

The size of bricks used in masonry works of the Northern Division, Ganges Canal, is 12 × 6 × 2½ inches; and when made by contract in Hindoostanee clamps, are paid for at the rate of Rs 475 per lakh; pucka or well-burnt bricks only are taken from the contractors. On the Western Jumna Canals, pucka bricks 12 × 6 × 3 inches are delivered by contractors at the clamps for Rs. 450 per lakh, and pucka bricks 12 × 6 × 2 inches for Rs. 350 per lakh. Carriage from the clamps to work brings the price of the former up to 600 Rs. and the latter to 500 Rs. per lakh.

The sooner a Hindoostanee clamp is fired the better. I imagine that when about one-third filled, the clamp ought to be lighted, for the fire will burn more quickly, and more equably before the fuel becomes compressed and partly decayed than it would otherwise.

41. Memo. of the cost of one lakh of bricks burned in a Pajáwah (Mynpooree District), by Sergeant W. Johnstone, Overseer, Northern Division, Ganges Canal.

	Rs.	A.	P.
Cost of 1 lakh kucha bricks (contract), ...	60	0	0
325 hackery loads of litter, at 6 as. per load, ...	121	14	0
760 maunds oopla, Mynpooree weight (= 950 Co's. maunds), at Rs. 1 per 10 maunds, ...	76	0	0
120 maunds fire-wood (= 150 Co's maunds), ...	12	0	0
Labor—piling and burning bricks, including pay of chuprasee, ...	80	0	0
Sundries, ...	10	0	0
Cost of bricks at the clamp, ...	319	14	0

42. Extract from a Memorandum by M. P. Volk, on Brick-making, in the Third Division of the Ganges Canal Works, dated 15th December, 1851.

Village coolies have been principally employed on moulding bricks, and these turn out from 500 to 700 bricks per man per day. When regular moulders have been employed, the out-turn per man has been from 1,200 to 1,500 per day. The con-

tract rates for moulding vary from 55 to 70 rupees per lakh, according to the difficulty of procuring water.

The dimensions of bricks made and used in the Third Division, are 12 × 6 × 3 inches, and they have been burned invariably in the country kilns or native pajáwahs.

The fuel used in a pajáwah consists of all kinds of combustible refuse of towns and villages, and oopla and dung made into cakes well dried in the sun. Oopla and *huddy khuddy* (bones and pig's dung) have been weighed before being put into the clamp; of the former, from 1,500 to 1,800 maunds; of the latter from 300 to 600 maunds; and about 6,000 maunds of koorah (village refuse) are required for one lakh of bricks Small quantities of wood have sometimes been put into clamps, but it proved disadvantageous, and Mr. Volk thinks the use of wood and koorah conjointly is injurious.

The time occupied in loading a clamp varies from two to three months for each lakh, and the success of a clamp depends very much upon this item. Mr. Volk's experience has convinced him that the sooner a clamp is fired the better; and his rule has been that when 40 or 50,000 bricks were piled into the clamp, it should be lighted; the progress of the fire being slow, any number of bricks can be piled afterwards.

The time required to unload a clamp when properly cooled depends upon the labor employed, but the period required for cooling is very long, and sometimes the process of loading is obstructed by heat, eight or ten months after fire has been set to the clamp.

A properly managed and successful clamp ought to turn out from 80 to 85 per cent. of well burned bricks.

Expenses incurred in brick-making in the Third Division, during the years 1850 and 1851, were as follows:—

Total expenditure for thirty-two clamps made during the season of 1850, is Rs. 18,541-10-6; number of bricks piled is 3,696,080; cost of one lakh is, therefore, Rs 501.

Total expenditure on thirty-four clamps made during the season of 1851, is Rs. 15,652; the number of bricks piled is 3,477,529; cost of one lakh, therefore, is Rs. 450; or a saving on the former season of Rs. 51 per lakh.

The maximum cost per lakh in 1850 is Rs. 633; minimum Rs. 326; the maximum cost per lakh in 1851 is Rs. 567; the minimum Rs. 352. The largest kiln contained 315,900 bricks; the smallest 36,000. Supposing the total cost of a lakh of bricks to be 1, the expenditure on the several items required in brick-making, has the following proportions:—

Particulars of expense.	In 1850.	In 1851.
Establishment, ...	0·116	0·097
Carting koorah, ...	0·393	0·426
[illegible]	0·092	0·127
[illegible]	0·146	0·123
[illegible]	0·052	0·050
[illegible]	0·192	0·171
[illegible]	0·009	0·006
Total, ...	1·000	1·000

No compensation has been given for koorah, but its *conveyance* is the most expensive item in brick-making, being equal to two-fifths of the total cost for a lakh. The total expense incurred on account of fuel is equal to three-fifths of the total cost of a clamp.

Mr. Volk charges at his works Rs. 900 per lakh for pucka bricks, Rs. 300 per lakh for peela ones. These rates are higher than the real cost on the last two year's operations, *but they are maintained to cover the losses suffered by failures at the* commencement of operations. The actual cost of a lakh of pucka bricks at the kiln is about Rs. 650 The rate paid to contractors for pucka bricks is Rs. 500, but contractors can only be found near large towns, where koorah is plentiful.

Mr. Volk considers the native clamps (pajawah) preferable to any description of kiln he has seen used in India; the size of these pajáwahs should depend on the quantity of bricks to be loaded, and the kind of fuel to be used. He considers also, that large clamps are more advantageous than small ones.

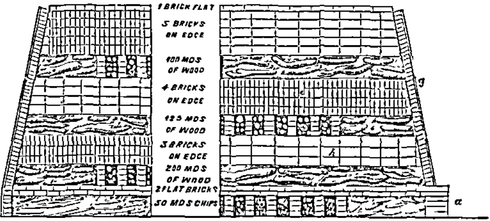
43. In all these "clamp" systems, there is much loss by breakage, in consequence of the upper courses of bricks sinking on the consumption of the fuel underneath them. The distribution of heat also (at least in clamps of the large size formerly in use at Roorkee), is unequal; some parts of the clamp producing larger masses of vitrified material, whilst in others, the bricks are but half-burned.

Various experiments were made in Bengal, and the result published by the Military Board, in 1827 and 1828, on the burning bricks in *clamps*, both with wood and coal. The clamps were built with flues as described in the English *kilns*, but smaller, and filled with well-dried chips or brush-wood. For the fuel above the flues, or *choolahs*, green wood was preferred, as retarding the fire; wood-loaded kilns generally burning too rapidly, and causing great loss by vitrifying the bricks in the centre The wood was split up into pieces not exceeding 4 or 5 inches in thickness, and so arranged, as to leave level surfaces for the layers of bricks to be laid upon. The flues were 2 feet high and 9 inches wide, with three bricks laid flat on them, having narrow intervals to allow of the fire ascending from the flues. The clamps were finished with alternate layers of brick and fuel, the bricks being laid touching each other throughout, the interstices formed by their contraction under the great heat, being sufficient to ensure the firing of the upper layers of *fuel. The sides of the clamp were then built* up with mud, broken kucha bricks, &c., and well plastered with mud to exclude the air.

44. Another construction by Capt. Bell, as described seems well adapted to prevent the sinking of clamps when wood is used as fuel. The wood is everywhere contained in flues crossing each other at right angles, the walls of which are supported by layers of brick-on-edge, completely covering the area of the clamp.

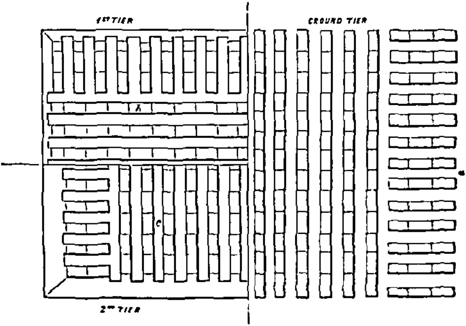
The ground layer of four flat bricks being laid with equidistant flues,

they are filled up with light wood and dry chips, over which two bricks are laid flat; on this is formed a second set of flues, running acoss the



CROSS SECTION LONGITUDINAL SECTION

PLAN



ground flues, and, after filling up between the flues with wood, the whole area is built over with three bricks-on edge, the length of the bricks running in the same direction with the flues and wood The full height is

formed by an alternation of flues*, and solid masses of bricks as shown in the plan annexed.

To close the clamp, extend the flue opening as at *a* (*see* section) one brick in length, and cover it with two flat bricks. Then build up with one brick breadth-ways, the outer coating as at *g* (with half-dried bricks, or any kind), over which straw (well wetted) is laid on the slope from the top downwards, giving it a good coat of mud plaster. The mud should not be thickly laid on, but well rubbed into the grass. If thick, the heat of the fire and sun makes it peel off, and admit the air, before the fire has gone through the clamp.

One great error appears to consist, in putting large masses of wood into the *upper* tier flues: it is thus that so much material becomes vitrified The ground flues ought to be filled, (but not choked) with good dry fuel intermixed with chips, so as to communicate quickly through the whole. The wood of the first tier should be reasonably large, with some small pieces or chips; and in every higher tier in succession they should be less in size as well as in quantity; because, as all the fire and heat rise from below, the higher tier has the advantage of all the foregoing flue fires in addition to its own. Previous to its ignition, too many bricks should not be piled above the wood, however great the quantity of the latter, or they will be irregularly burnt, and much fuel wasted.

MEMO, OF TWO SMALL CLAMPS AT AMPTHA, BURNED BY CAPTAIN BELL.

	12-in. brick.	Mds. of coal.	Mds. wood in chulah.
1st kiln Clamp, -	24,000	104	60
2nd „ -	40,000	159½	90

The bricks taken from which were all red, well burnt, and not more than 500 unserviceable.

45. *Circular Brick Clamps.*—This kind of clamp will be found superior to native *pajáwahs* in percentage of first-class out-turn, and a very great advantage in their use is, that the exact quantity of bricks and fuel loaded into the clamp can be determined by measurement, which cannot be done in the case of *pajáwahs*, where the officer in charge is almost entirely at the mercy of his mates and moonshees with regard to the expenditure of fuel. These Clamps can only be used when *oopla* is obtainable in large quantities; where *koora* is chiefly procurable, common pajáwahs should be used. A clamp containing a lakh and three-quarters of 9-inch bricks, should be about 64 feet in diameter in the lowest course of bricks, and

* Two rows of bricks laid flat, seem to be requisite above *each* set of flues, to prevent bricks on-edge from falling into them, whilst the fuel is being consumed.

ought to take 14 days to load, 14 days to burn out, and a month to cool down. The thicknesses of fuel given on the drawing, are those which should be used in the hot weather, but, at the commencement of operations in the cold season, the thickness of oopla in the courses should be increased by about 20 per cent. The average out-turn through the season, if care is taken to regulate thickness of fuel properly, should be about 70 per cent. first-class, and 10 per cent. second-class, bricks, per 100 kucha bricks loaded. The following memorandum is adapted and modified from one in use in the Jullundur Division:—

Memorandum for guidance of Subordinate in charge of kiln-yard, in loading Circular Clamp.—1. Prepare the ground by describing a circle about 64 feet in diameter, and form the ground into a neat and regular inverted cone, depth of which may be about 18 to 24 inches. Spread a bed of ashes over this, if available; if not available, use 3 inches of *koora*.

2. Loading is not to commence until the bricks and fuel required for the clamp have been all collected at site.

3 Commence the clamp by a course of brick-on-edge (peela 12-inch bricks if available) arranged as shown in plan of flue course. This course forms a succession of flues into the heart of the clamp, and allows the fire to spread regularly from centre to circumference in the lowest course of fuel.

4. Lay on the flue courses, a course of *oopla* of equal thickness packed regularly. when completed, beat this down slightly with wooden beaters, and spread over all about 2 inches of koora No other fuel than oopla and koora is to be used in any part of the clamp. Koora is infused to prevent the oopla burning too rapidly.

5. On this, lay a course of brick-on-edge, then a second course of oopla and koora, as shown in the drawing, and so on, beating down each course of oopla before the koora is laid on it, the beating to be harder and continued longer in the higher, than in the lower, courses. The surface of each coat of koora is to be formed into a neat inverted cone before laying the bricks over it, and each course of fuel and bricks must be measured by the subordinate in charge before the next course is laid, and the actual measurements recorded in the register.

The bricks are to be laid as close together on edge as possible, and it is not necessary to leave any openings between them, as the fire spreads with sufficient rapidity when the bricks are laid close. The outer rings of the courses of bricks should be of peela bricks, if any are available, as they will probably burn pucka, and become useful. Care must be taken to leave a vertical flue of about 12 inches diameter in centre of the clamp, through which the kiln is to be fired; it is to be kept covered by an inverted *gurrah* as the work goes on, and is to be cleared by pushing down a long bamboo before lighting the clamp, which is effected by dropping live charcoal down the flues, and when the fire has taken, this flue is to be closed.

6. The outer surface is to be smoothed off with oopla, the steps left being filled up, commencing from the top, and a course of cakes of oopla packed on edge laid over this The whole is to be finished off with a coat of 3 inches of koora covered with ashes, and a straw covering and leeping are unnecessary. When the outer coat is completed, a kutcha wall of refuse bricks in mud is to be built up all round the

clamp, to a height of 4 feet or so, flues communicating with the flue course being left all round, which are to be closed when it is found that the clamp is burning properly, and are to be opened when required to regulate the spread of the fire.

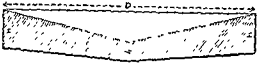
7. As the burning goes on, any openings which may form are to be closed at once with oopla, koora and ashes, and a party of coolies must be kept at this work night and day for the first few days after lighting the kiln If the diameters of the courses of bricks are made to diminish 4 feet in each course up to the 8th, and 6 feet in the courses above the 8th, little trouble will be experienced in the above respect, and the courses should also be stepped off as shown in the drawing ; but if these points be not attended to, great trouble and loss will be caused by bricks falling down the sides as the clamp settles. If fire breaks out, it should be at once smothered with ashes.

8. Unloading may be commenced so soon as the clamp cools down, but care must be taken not to open it prematurely, as if opened before the bricks have become annealed, great breakage will certainly take place in the process of unloading, and the bricks will be rendered brittle

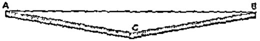
9. Clamps are to be unloaded from the top downwards in successive courses as loaded, and the state of each course is to be recorded in the register by the subordinate in charge, for guidance in regulating the thickness of fuel in future clamps. The ashes are to be regularly removed from each course in baskets, and used in forming a bed for a new kiln or in filling excavations.

Measurements of courses of fuel, &c.

To find cubic feet of oopla in any course.—Measure diameter D in feet with a tight tape, and measure H and h in inches. Then, cubic feet oopla $= \frac{\text{area square feet}}{18} \times (H + \frac{1}{3} h)$.



To find cubic feet of koora in any course.—Measure diameter AB $=$ D with a tight tape; sides of cone ACB $= D_1$ with a loose tape; measure the thickness in inches $= h$, use a new diameter $= \sqrt{D \times D_1}$, and area of circle to this diameter.



Then, content of course in cubic feet $= \frac{\text{area of circle}}{12} \times h$.

To find 9-inch bricks in any course.—Take measurements as for courses of koora, being careful to take the mean measurement where steps are given on the exterior circumference of course of bricks.

Then—

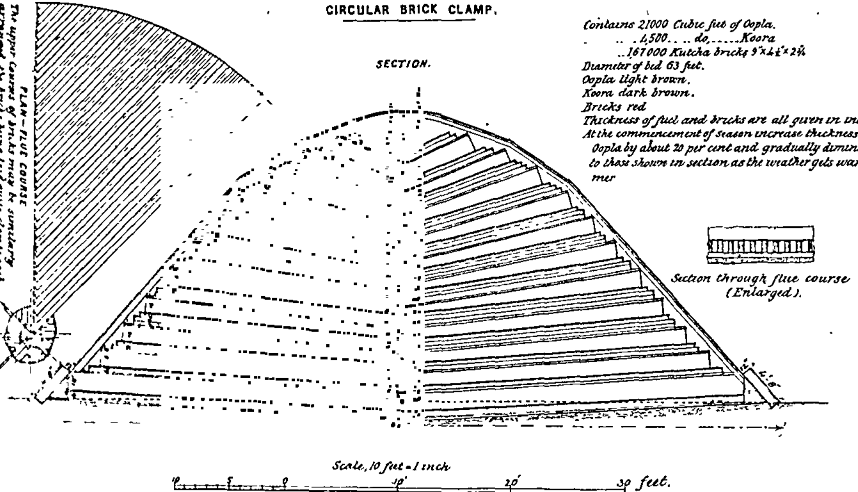
$$\left.\begin{matrix}\text{Content of course}\\ \text{in 9-inch brick}\end{matrix}\right\} = \left\{\begin{matrix}\text{area of}\\ \text{circle}\end{matrix}\right\} \times 1{\cdot}165 \times h'$$

the constant 1·165 will vary according to the closeness or otherwise of packing of the course, and also according to the size mould used, and should be determined by counting the bricks actually laid in a sector of some selected course.

The mode of obtaining contents of top, and of exterior covering is sufficiently obvious.

It is recommended that a Slide rule should be used for working out the content of the courses ; it will be found much more rapid in use than a table of areas of circles, and will give contents with sufficient accuracy for all practical purposes.

CIRCULAR BRICK CLAMP.



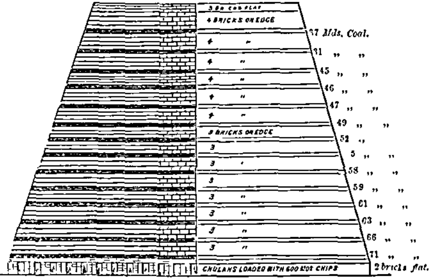
If the subordinate in charge is unacquainted with the use of the slide rule, he should be provided with a set of tables, as the labor of calculating out the content of the courses with pen and ink, would be very great, and in fact would be impracticable if the operations were carried out on a large scale.

46. Captain Sage, Executive Officer, Guttaul Division, Public Works, gives the following comparative estimate of the cost of burning bricks with coal and wood; by which it appears that with wood at Rs. 16 per 100 maunds, and coal at Rs. 37-8 per 100 maunds,* the latter is much the cheaper.

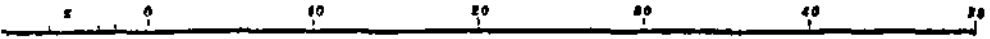
No. 1.

Burnt with Coal at Bhoorsoot.

Small Wood and Chips, 600 Mds
Coal in layers, ... 7.0 „
Bricks, ... 206,000



GROUND PLAN SIMILAR TO THAT OF NO 2



	R.	A.	P.
100,000 bricks, 12 inches, ...	53	0	0
Kilning „ „	26	0	0
1,000 bundles grass, ...	2	0	0
20 coolies clearing the ground, at 2 as each, ...	2	8	0
650 maunds of sands, at Rs 3 per 1,000 maunds, ..	19	8	0
Bamboos, rope, &c., ...	1	0	0
300 maunds of wood, at Rs 16 per 100, ...	48	0	0
375 maunds of coal at 6 as. per maund, ...	101	10	0
Total Rs., ...	292	10	0

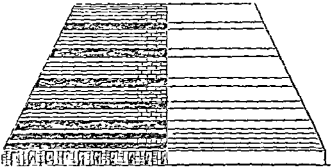
Actual produce excluding loss by breakage, &c , 90,000 bricks, at 326 Rs per 100,000

* About 21s. per ton.

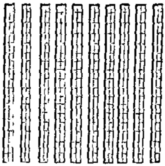
No. 2.

Burnt with Wood at Julapoor.

75,000 Bricks.
1,158 Mds. of Wood.



Plan of Chulahs.



	R.	A.	P.
100,000 bricks, 12 inches, ...	53	0	0
Kilning „ „	26	0	0
1,000 bundles of straw, ...	2	0	0
20 coolies cleaning the ground, at 2 as. each, ...	2	8	0
650 maunds of sand, at Rs. 3 per 100 maunds, ...	19	8	0
Bamboos and ropes, ...	1	0	0
1,600 maunds of wood, at Rs. 16 per 100 maunds, ...	256	0	0
Total Rs, ...	360	0	0

Actual produce excluding loss by breakage, &c , 75,000 bricks, at 480 Rs. per 100,000.

Besides the advantage of cheapness, coal is shown to be in many other respects superior as fuel, to wood; the space occupied by it between the layers of brick is so much smaller, that the clamp sinks much less, and its outer casing is less deranged. The wind which interferes with the gradual and equable process of the fire is thus better kept out. The loss by breakage is likewise much less, and the bricks from being burnt more slowly are more compact. The coal should be broken into pieces not exceeding one inch in diameter. In kilns, likewise coal must have like advantages over wood, except as regards the greater displacement of the casing of the clamp; the permanent walls of kilns not being liable to this contingency.

47. Hoffmann's Patent Kilns.—The grand object of this invention —economy of fuel—is materially assisted by particular attention being paid to a few leading points; and first, by selecting a dry, well-drained site; as any damp rising from the earth is to be carefully avoided; for, should this be present, it not only takes fuel to generate this moisture into vapour for discharging it by the flues, but it has the further serious effect of retarding the burning of the kiln, and damaging the burnt

bricks, which would show cracks caused by the vapour rising from the ground.

Drainage.—After the soil has been taken out, it is of the utmost importance to well-drain the whole site to a deeper level than the lowest flue. From the smoke-chamber round the chimney, a drain is to be laid at a lower level than any of the foundations, and all drains from flues, &c., should have an inclination towards the central chamber, and delivering into this drain. The chimney foundation, likewise, is to be supplied with a drain to carry off the condensed steam running down the inside wall of the stack.

Foundation of burning chamber.—The foundation of the two walls forming the annular burning chamber is to be carried down 2 feet 6 inches below the floor-level, as shown in plan, for, if the material beneath the floor is composed of clay, or any substance that will contract on exposure to heat from firing the goods over it, it is obvious the foundation would give way, open, and admit air, which is a serious drawback to the working of the kiln. The floor of the burning chamber is to be formed of hollow chambers as shown in sections (*g h*) and (*i k*) of the *Plate*, being closely covered over with bricks, on the top of which a stratum of clay is packed about 9 inches thick, and on this rests the paving of common bricks. The lining inside the kiln, including the drop arches at the end of each chamber, is to be made of fire-bricks, or bricks which will not contract under repeated burnings, being able to resist a greater heat than the clay to be burned.

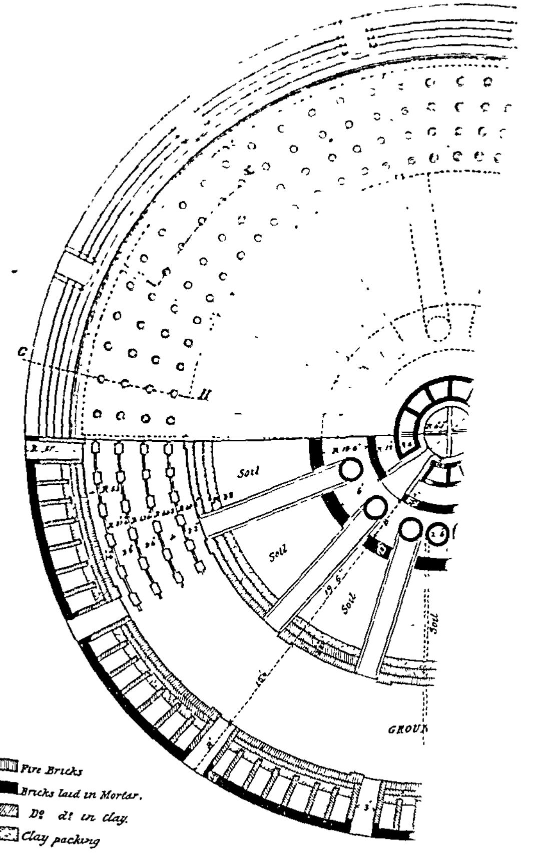
Battered walls.—The outer battered walls of the kiln taking up the pressure from the arch, are to be built as shown of common bricks, laid in mortar, *not* bonded with the wall of burning chamber, allowing the latter free motion as required through the heat passing through the kiln. In the packed space between the outer-walls, and walls of burning chamber, cross-walls or tie of 4½ inches work, (it is shown in the plan *one brick*, but *half brick* is quite enough) are constructed, and bonded with the battered walls, but free of all connection with the inner wall; the object being to resist better the thrust during expansion, instead of solely depending on the packing material.

Chimney.—The chimney, which is of a very light construction, consists in its horizontal section, of two rings of 9 and 4½ inches brick-work, respectively. The 9-inch wall is carried up to about 30 feet in height, and then

both rings are only built with half a brick each. These rings are bonded and strengthened by radial ties reaching from the base right to the top of the chimney. There are altogether 12 such ties. The short inner tube is constructed inside the chimney to protect the brick-work of the latter, in *case an intense heat should, through some cause or other, pass into the* chimney, as may happen at the end of the season in burning the last chamber, by allowing the gases of intense heat or the flame to pass *direct* into the chimney. This chimney construction is both cheap and strong, and forming an air chamber round the inner wall, the latter is well protected against cooling, which is very important, as the waste steam and smoke possess a very low temperature. At the base, the chimney is provided with four apertures forming the communication with the smoke chamber.

Bricklaying.—The whole structure of the kiln can be executed with bricks laid in mortar in the usual manner, with this one exception, that the two side walls, arch and floor, forming the annular chamber, are to be *built with bricks laid in clay mixed with sand to the texture of a good* loam. For making firm work, this clay should be made up into a slop of the consistence of thick cream, and *not* used as mortar is generally employed, making a thick joint between each brick, and the next following one. The slop or clay being placed conveniently for the workman in a water-tight box, he takes a brick, and dipping those surfaces he wishes to unite in the slop, and well coating them with it, he lays the brick in its place, at the same time forcing it into as close a contact as possible with those next to it. He then proceeds with another, and so on. It is therefore, obvious that those bricks will rest closely one upon the other with only a thin bed of clay cementing them together, and when the kiln has been burnt round once, it will be found the strongest mode of structure for withstanding the *expansion and contraction to which such walls are exposed. The outside* walls are built in mortar, as well as the *flues*, *chimney*, and smoke chamber, although in many cases even the smoke chamber is constructed with bricks laid in clay.

Arches.—In turning the arches of the chamber, a centre must be made to fit one chamber, and this can be lowered and removed to the next chamber in one piece. At each end of the chamber, a dropping arch is built of one brick projection to obstruct the draught along the top of the kiln, while they likewise serve as a support against which are placed the inter-


C
L
K
H
R M
Soil
Soil
Soil
Soil
19. 6
15
GROUN
Fire Bricks
Bricks laid in Mortar.
D° d° in clay.
Clay packing

both rings are only built with half a brick each. These rings are bonded *and strengthened by radial ties reaching from the base right to the top of* the chimney. There are altogether 12 such ties. The short inner tube is constructed inside the chimney to protect the brick-work of the latter, in case an intense heat should, through some cause or other, pass into the chimney, as may happen at the end of the season in burning the last chamber, by allowing the gases of intense heat or the flame to pass *direct* into the chimney. This chimney construction is both cheap and strong, and forming an air chamber round the inner wall, the latter is well protected against cooling, which is very important, as the waste steam and smoke possess a very low temperature. At the base, the chimney is *provided with four apertures forming the communication with the smoke* chamber.

Bricklaying.—The whole structure of the kiln can be executed with bricks laid in mortar in the usual manner, with this one exception, that the two side walls, arch and *floor, forming* the annular chamber, are to be built with bricks laid in clay mixed with sand to the texture of a good loam. For making firm work, this clay should be made up into a slop of the consistence of thick cream, and *not* used as mortar is generally employed, making a thick joint between each brick, and the next following one. The slop or clay being placed conveniently for the workman in a water-tight box, he takes a brick, and dipping those surfaces he wishes to unite in the slop, and well coating them with it, he lays the brick in its place, at the same time forcing it into as close a contact as possible with those next to it. He then proceeds with another, and so on. It is therefore, obvious that those bricks will rest closely one upon the other with only a thin bed of clay cementing them together, and when the kiln has been burnt round once, it will be found the strongest mode of structure for withstanding the expansion and contraction to which such walls are exposed. The outside walls are built in mortar, as well as the *flues, chimney,* and smoke chamber, although in many cases even the smoke chamber is constructed with bricks laid in clay.

Arches.—In turning the arches of the chamber, a centre must be made to fit one chamber, and this can be lowered and removed to the next chamber in one piece. At each end of the chamber, a dropping arch is built of one brick projection to obstruct the draught along the top of the kiln, while they likewise serve as a support against which are placed the inter-

cepting wrought-iron dampers for dividing and separating the chamber, as will be explained below.

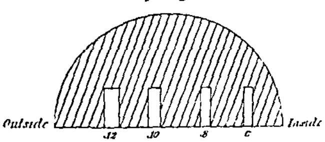
Radiation.—The main arch of the annular firing-chamber is covered with a stratum of clay from 4 to 6 inches thick; and above this, as well as between battered wall and wall of burning-chamber, as well as the whole space between burning-chamber and smoke-chamber, is to be filled with soil or sand, to prevent any heat from escaping, and to prevent the possibility of any damp or moisture finding its way within reach of the heat of the burning-chamber. For this reason, it is most desirable to construct a roof over the kiln, under which large quantities of goods can be dried, while at the same time, it affords a shelter to the men attending to the firing of the kiln, who, exposed to the changes of the weather, more particularly during the night, cannot be expected to attend to their duties with punctuality. If, however, no roof is provided, the whole top surface should be closely paved on a thick bed of mortar or cement, and when finished, well grouted with cement, to prevent the possibility of water passing through it, at the same time giving the surface a good fall to carry off all water falling upon it.

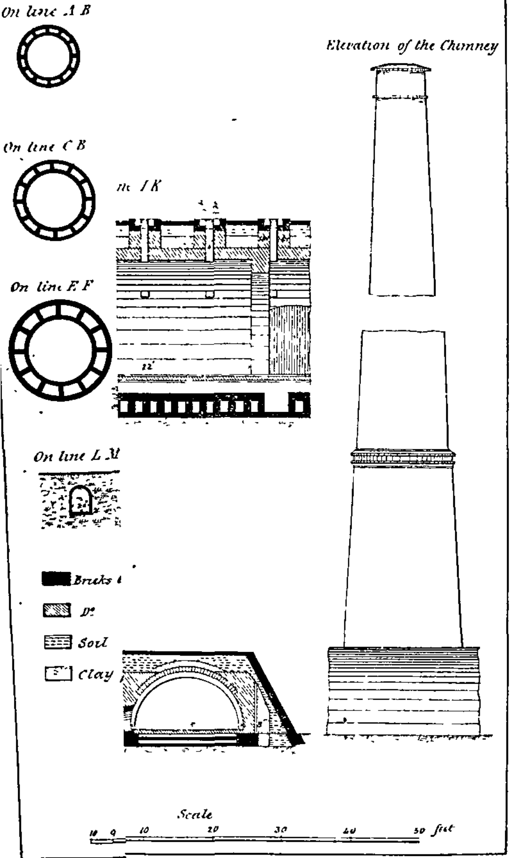
Iron-work.—The iron-work for each kiln of 14 chambers consists of 14 valves for regulating the draught, and they are built in, as shown in *Plate* VII. on the outlet of each flue in the smoke chamber. The adjusting lids, when seated, should rest on a bed of sand to secure an air-tight joint. From the centre of these lids, a long adjusting rod passes up through the arch of the smoke-chamber, and by means of a cast-iron plate and set-screw, it can be regulated to any height required. On the underside of these lids, are fixed three or four iron-bars, forming a guide to the valve, which, on being lowered, adjusts it properly in its place. Each firing-hole has an iron-pipe built in with a cast-iron cap fitting in a bed of sand air-tight. Of these 280, or 20 for each chamber, are required. Besides these castings, each kiln requires two large intercepting sheet-iron dampers as shown in *Plate* IX. The damper is brought in through a door-way and placed in its several partitions one above the other, against the projecting arch, while in removing the same, the top parts are lifted, and the lower parts drawn through the door-way, and after that, the top parts are lowered, and removed in the same manner. It is only for convenience sake to have *two* dampers for each kiln, that the work of the same may not be interrupted while the damper is removed.

While one damper is placed several compartments in front of the fire, a second damper is placed in *front of the chamber to be filled;* thus the first damper may be removed without interrupting the draught, as the second damper is ready to cut off the draught in similar manner, allowing the waste gases to pursue their course also through this compartment recently filled with green bricks. The best method of placing the damper in its place is more minutely explained in the description of working and lighting the kilns.

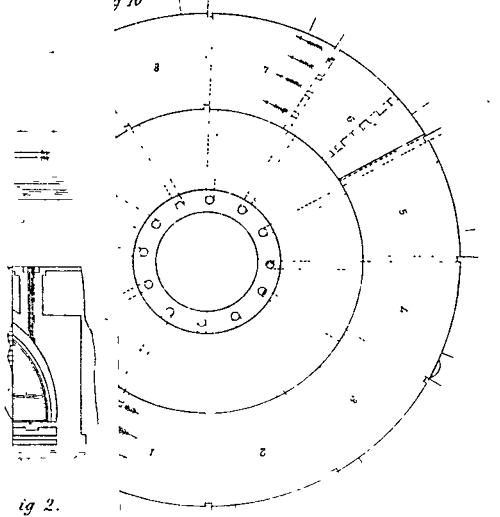
Setting.—As soon as the construction of the kiln is completed, a number of fires are lighted in front of all flues leading to the chimney, as well as in various parts of the burning chamber, for several days, to drive off partially the moisture contained in the brick-work and floor. After this has been done, the next operation is setting or placing the bricks in the kiln ready for burning. The setting is done in the usual way as adopted in the ordinary kilns, with the exception that special care is required to form, immediately under each of the feeding holes, in the arch of burning chamber, (*Plate* VIII., *Fig.* 4), vertical pits from crown of arch right down to the floor, to allow of a passage for the fuel inserted from above to fall right down on the floor. Each of these fire-holes should be formed about 12 inches wide, down to within six courses from the floor, where they should be increased to 18 inches square, for the reception and combustion of the fuel. As in this kiln there are four circular rows of fire-holes, consequently four circular flues (as shown in *Figs.* 1, 2, 3*a*, 3*b*,) are to be formed along the floor, connecting one fire-hole with the one in advance, as will be readily understood on reference to the annexed drawings.

These flues form the passage for the flame to travel along the kiln; they are made four courses high and are covered by the fifth course of bricks. In case the bricks are placed very damp in the kiln, it is well to raise the height of these flues a few courses, to allow the steam sufficient room to escape. If the kiln is in full operation, it is well to make the inside flue narrowest, say 6 inches, and increase the width and height of the other central flues, as shown in sketch in margin; so that the outside channel,




On line A B
Elevation of the Chimney
On line C B
on I K
On line E F
12
On line L M
Bricks
D°
Soil
Clay
Scale
10 0 10 20 30 40 50 feet

7 10



ig 2.

being the widest, say 12 inches, and highest, say 24 inches to 30 inches, will draw the fire more to the outside of the kiln; as naturally, the draught has a tendency to pass along the shortest way at the innerside of firing-chamber, and thus some difficulty may arise to keep the fire proceeding with the same rapidity along the outside flue. *Figs.* 1, 2, 3*a*, 3*b* illustrate how the courses of bricks are placed alternately one upon the other.

For the lowest course along the floor, it is advisable to take for the first *time* of burning, *burnt* bricks instead of green bricks, as the steam from the floor may soften the bricks placed immediately above it, which being unable to carry the weight of the whole bulk of bricks, would give way, and at once stop up the draught along the floor, and cause delay and annoyance. This first course, as illustrated in *Fig.* 1, is placed rather *open, (leaving one inch space between each brick,) at an angle from the inside* to the outside wall. The second course is shown in *Fig.* 2, and the bricks are placed in the direction of the circular flues, on which again a skintle is placed,* *Fig.* 3*a*, upon which again the bricks are set as in *Fig.* 1; then *Fig.* 3*b* shows the fifth course covering up the central flues. The next courses *are again set alternately as explained in Figs.* 1 and 2. The direction of every alternate course should be changed; while in one course the length of the brick is set in parallel lines with the walls of the kiln, and taking the same onward line of draught, (*Fig.* 2,) the next course above it should be at an angle from the inside to the outside wall, (*Fig.* 1). Thus the compartment is filled right up to the crown of arch.

In setting, the workman commences at one end of the chamber, where the large intercepting damper is placed, and continues so until he has five chambers filled without interruption. In the meantime, the doorways are built up with burnt bricks, and made quite air-tight by filling in sand between two brick walls as illustrated in *Fig.* 6. The men having filled chambers 1, 2, 3, 4, 5, *Fig.* 10, the large intercepting damper is inserted through the door-way of compartment 6, and placed in front and across the chamber 5. *This damper as shown in Fig. 5, consists* of three parts built up, and sliding in each other. The special plan in *Plate* IX, explains this damper more clearly, and further reference will be made to it on page 77. It is of great importance to place this damper in such a position that it forms an absolute air-tight division, as no air should be allowed to enter at any place, nor the heat escape. The same care is to be taken with the door-ways, which should be daily inspected several times.

* "*Skintling*" is stacking bricks with spaces between them

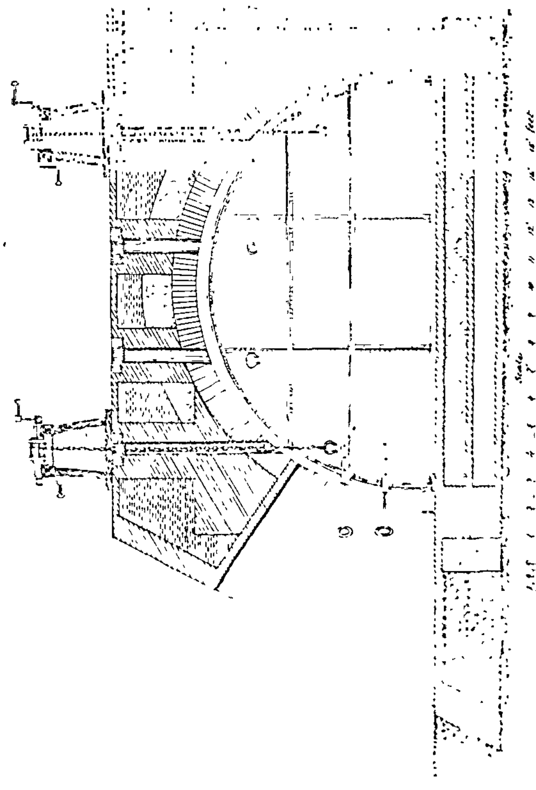
In the meantime, while this is done, the chambers 7, 8, 9, 10 and 11 are filled with green bricks, as has been done with 1 to 5 inclusive, and a second intercepting damper introduced through the door-way 12, is placed across, and in front of chamber 11, *Fig.* 10, made air-tight as well as all the doorways leading to compartments 7, 8, 9, 10, 11. It may be here proper to observe that it is desirable to fill the kiln for the first time of burning at least with bricks as dry as obtainable, as the new construction contains so much moisture, which is to be got rid of gradually, and excess of steam from bricks and building may injure the bricks to be burnt materially.

Lighting.—In chamber No. 12, in front of chamber No. 1 (*Fig.* 10). as well as in chamber No. 6 in front of chamber, No. 7, temporary walls are to be built across the section of burning chamber, as explained in detail in *Fig.* 8, provided with four common kiln fires, *Figs.* 8 and 9, corresponding with the four central flues formed in the setting of the bricks along the floor. The valves in the smoke chamber Nos. 5, 4, 3 and 11, 10, 9 are to be opened entirely, while all others remain closed, bedded air-tight in sand. Fires may now be lighted in the two walls, respectively, or in the eight permanent fire-places between chambers 12 and 1 and 6 and 7. These fires are kept *very low* for 48 hours at least, after which time they may be *gradually raised* for another 48 hours, until after about five days, the fires must be kept up to their *full intensity*. Of course all the caps covering the feed pipes in the arch are to be kept quite closed, and bedded air-tight in sand. The first sign of the fire taking effect, is a volume of steam escaping the chimney. If too much steam is created, which can easily be ascertained by lifting a few caps, out of which the steam will evolve in large dense masses, such caps may be kept open for awhile, as this is a sign that the chimney is not able to draw off the volume of steam as rapidly as it is created through the effect of the fire.

If *too much* steam is confined, the bricks become soft, and in many cases, the lower courses not being able to carry the weight of the bricks above them, they give way, and thus interrupt the draught along the floor, while many bricks will be spoiled and unfit for use. In this way the fire is kept up from the temporary walls, until the bricks in the compartments near the intercepting dampers of chambers 5 and 11 are pretty well dry, which may be ascertained from the quantity of steam escaping by the chimney, which should be very little for about five or six days, making in all about 10 or 11 days. Now the fires in the temporary wall between chambers 7

HOFFMAN'S BRICK KILNS.

(Intercepting Damper)



and 6 are extinguished: chamber 6, which has been empty, is filled with green bricks, as dry as they are obtainable, with the least possible delay, as soon as men are able to set, after having removed the temporary wall.

The chamber 6 thus being filled, the damper separating compartment 5 from 6 is removed, the door-way of chamber 6 built up and made air-tight, the valves 3, 4 and 5 are closed carefully, not to allow any air to escape, nor to enter the kiln, while the valves 9, 10, 11 remain wide open, and the fire at the temporary wall 12 is increased to the greatest possible intensity. As soon as the chamber 1 is *hot enough*, the burning is assisted by throwing in fuel through the feed-holes near the temporary wall; if the fuel reaching the floor *ignites*, continue to do so through the first and second row of feed-holes; and through the fires from the temporary wall, as well as from above. As the heat proceeds, the firing likewise proceeds at the same rate from above, and as soon as the fire reaches chamber 3, the fire in the temporary wall is decreased, and a little air is allowed to enter at the permanent wall, *by taking a few bricks out of it from under the arch.*

As soon as the fire has advanced as far as chamber 4, the valve of chamber 9 may be closed, the fires in the temporary walls put out, the *fire-places filled up*, a larger opening formed in the upper part of the temporary wall for access of air; and when the fire has reached chamber 7, the temporary wall at 1 may be quite removed, allowing the air entering through the door-way of 12, free access to cool the burnt-bricks in 1. As soon as the fire has advanced as far as 8, chamber 1 is emptied of burnt-bricks, chamber 12 filled with green bricks, and the intercepting damper removed from 12 to 1. The valve 10 is closed, and 12 opened, after having the door-way of 12 built up air-tight as illustrated in *Fig.* 6. Now the kiln is in working order, and the fire will advance every day along one chamber; therefore one chamber is *daily* to be drawn, and one chamber to be *filled, the large intercepting damper being removed and advanced. One valve is closed every day, and one* in advance is opened, thus it is found expedient to have generally two valves open. If, however, the kiln is very dry, and the bricks placed in the kilns quite air-dry, it will often be found sufficient to open only one valve at a time. *It is not necessary* to leave *the whole chamber* (6) empty, as the temporary wall may just as well be built as shown in dotted lines nearer the damper *Fig.* 10, and the little place left may sooner be filled or left *half filled;* that is, the bottom part to guide the flame, while the top part may remain empty,

which would permit a shorter interruption of the working of the kiln. Of course, while the temporary wall is drawn and chamber (6) set, the dampers or valves 10 and 11 should be almost closed, so as not to draw in more cooling air than is necessary to enable the workmen to operate on chamber (6).

The fire on the kiln should always extend over at least *ten rows of feed-holes*, and as soon as the row in advance is ready to ignite the fuel at the bottom, one row in the rear is left off firing, and thus it regulates itself. It is very important to feed at *regular intervals, to arrive at the utmost* saving in fuel and regularity in burning. Presuming there are *nine* rows of holes to be fired, each hole should be fed at intervals of 15 minutes:—

1	2	3	4	5	6	7	8	9
O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O

At the full hour, row Nos. 1, 4, 7 are to be supplied with fuel,
Five minutes past the hour, Nos. 2, 5, 8,
Ten " " " " 3, 6, 9,
Fifteen " " " again " 1, 8, 7,

and so on. If, sometimes, it should be found some feed-holes require no supply, the fuel not being sufficiently consumed, they may be left out, but this will scarcely happen if the firing is attended to regularly.

It may be well to describe the working of the kiln in a few words to understand and appreciate the principle thoroughly. The cold air can only *enter the annular chamber through two door-ways, viz., one for drawing*, and one for removing the bricks. As it proceeds onwards in its line of draught to the chimney, it enters the first of the now cooling chambers, by which it is warmed. As it percolates amongst the bricks in the second chamber, its temperature is considerably raised; through the third, it attains a high burning heat; and in the fourth, it reaches a glowing heat almost as high as the burning-bricks. With its temperature thus raised, it now passes the two burning compartments supplied with fuel, and mixing with the hot gases from the fire, perfect combustion in close contact with the goods is the result. Passing on from the burning chambers, it passes the 7th, in which the bricks are absorbing the waste heat, and they are *brought to a low red heat before any fuel is supplied*; the 8th chamber is warmed to a good heat, the 9th is dry and warm, while the 10th is

steaming and drying off; while the moist gases and products of combustion of a *low temperature* escape into the chimney.

The only skill required of the fireman is to judge when he has arrived at sufficient heat, and this he can easily learn by looking through any of the feed-holes, while he can *retard* or quicken the progress of the fire by closing or lifting one or more valves. He will require a strong draught when a new chamber is added, for 8 or 10 hours, while after that time for the remaining 14 hours, sometimes one valve open will be found sufficient. Particular care is to be taken to have the caps of feed-pipes always well screwed down in the sand; to see that the intercepting damper does not admit any air; to examine all closed valves, that they are bedded well in sand; and frequently to inspect the built-up door-ways, that they may prevent any cold air from entering the kiln. The attendant should frequently go into the smoke chamber, and inspect the valves to see whether they close air-tight in a bed of sand, which he can soon learn from a whistling noise, or by moving a candle round the seat. For this purpose, a *manhole* should be provided to allow access to the valve chamber.

In using coal for fuel, the fireman has a small hook and scoop, the one for handling the feed-cap, and the other for supplying coal. He should not keep the cap longer off the feed-pipe than is just required to supply the coal with his other hand, and he should insert a very little at a time, perhaps, ¾ pounds, just, enough to burn away during the 15 minutes rest. If too much fuel is supplied, the central flues will be stopped up through the accumulation of incandescent fuel, and the result would be an increase of heat at this particular place, melting the bricks, partly cutting off the draught, and thus interrupting the regular working and progress of fire, besides causing a waste of bricks. If *required to retard or even stop the progress of the fire, the valves in the* smoke-chamber must be *almost* closed, only leaving one valve about one inch open to prevent a back draught. The fireman's duty is therefore to feed at regular intervals, and keep the kiln everywhere air-tight, so that no cold air is allowed to enter except through the two open door-ways; and he will have no difficulty in burning sound bricks rapidly.

Plate IX., explains the construction of the intercepting damper in detail. The damper consists of three iron-plates A, B, C, one placed above the other; against the drop-arch D, is a shore in which the several pieces slide, while the damper is being removed. For removing the

50. Coloring of Bricks.—There are two methods in use for this purpose; one, by mixing certain coloring matters with the clay before burning, and another by dipping the brick in a coloring liquid after it is burnt.

The first method may be adopted when the coloring matter is available in sufficient quantity, and is not too expensive, but the second method is particularly well adapted for expensive colors, and admits of a great variety of colors being produced at comparatively little cost, and with little risk of failure or trouble.

The following three cases come under the head of the first method.

1.—*To make brown or stone colored clay into a light red when burned.*

Take 6 bushels of clay.
" 1 " yellow ochre.
" 1 " red brick, or *soorkee.*

Mix together and put through pug-mill, as described above.

2.—*To give a yellow color to bricks.*

For bricks of this color, the clay should be of the kinds known as Bedfordshire, Dorsetshire or Suffolk clay; but the yellow color will be increased, or produced from red clay even, by adding *red ochre*, and crushed yellow brick and pottery ware, if available.

3.—*For best blue bricks*, (*or tiles.*)

1 Bushel of ground flint.
1 " best fine clay *sifted.*
½ " ground glass (*common bottles.*)
3½ " French ultramarine.

Mix well together, and put through pug-mill as before.

Note.—This mixture and the next are rather intended for plain flooring tiles, or for filling in the colored portions of a pattern in an ornamental tile, than for bricks.

Bricks for these colors can be obtained more suitably by dipping in a coloring liquid, as explained further on.

Some coloring matters change their colors when exposed to great heat: for instance, red ochre burns yellow, and yellow ochre burns red.

The following retain their colors though exposed to white heat.—French ultramarine, light red, and indian red.

4. *For black bricks* (*or tiles.*)

1 Bushel of any clay, *not red.*
1½ " ground cinders, *not very fine.*
2 " manganese.

If for best work, such as terra cotta, add

1 Bushel of ground black glass.

Mix and put through pug-mill, as before.

Blue Bricks.—The color of the famous Staffordshire blue bricks appears to be due to the iron that is in the clay naturally, but the bricks assume the blue color only if subjected to a very great heat in the kiln. If burned to a certain pitch, they become red, like ordinary bricks, but if the fire be increased and continued for about twenty-four hours longer, the color changes into a very dark blue, or nearly approaching a black.

It is usual also to throw from two to three shovels full of common salt into each furnace, just before the fires are allowed to die out. This has the effect of producing a glazed surface upon the bricks.

They are much used for pavements in the side walks of the streets, as well as in buildings, and stand the heavy wear well.

In moulding them, the dry moulding system is used, but instead of sand for sprinkling the mould, they use a material known among the people as "swarf." This is merely the dust which collects from the grinding of edge-tools, and such like, and which can be had in considerable quantities in those localities. This dust helps to intensify the color of the brick, and in fact produces a kind of surface of iron matter upon the brick. But independent of it, there is sufficient iron in the clay to produce the color, *provided the brick be burned sufficiently.* Other clays will not stand the great heat necessary for these bricks.

51. The second method of *Coloring, by Dipping,* is a very simple process, and bricks or tiles colored in this way will stand any amount of exposure to the weather without losing their color. There is another good result from coloring in this way, the surface of such a brick will never take on any vegetable matter when exposed to a damp atmosphere.

The materials used for the coloring liquid are—Turpentine—linseed oil—and litharge; with coloring matter as may be required.

An earthenware box is provided, a few inches larger each way than a common brick, and it is half filled with a red liquid of about the consistency of thick cream.

The bricks, &c., to be colored are laid upon an iron plate, with a fire underneath. The place may be large enough to contain a couple or three score of bricks. The bricks are heated, not to a great heat, but too great to admit of their being handled.

They are then taken, one at a time, and dipped into the liquid in the box for a few seconds, then placed on a table to dry, which they do in a few minutes. They are then taken and slightly washed with the hard

or a bit of rag, in a trough of cold water, and placed aside to dry. This completes the whole process.

If the brick be open and porous, such as any common brick is, the coloring matter will penetrate about one-eighth of an inch; but for bricks containing a portion of glass and crockery, such as terra cotta, the coloring matter will not penetrate so far. However, in either case the color given to the brick is thoroughly *pucka* and lasting.

The following are the proportions used for some of the colors:—

1. *For dark red bricks.*

 $1\frac{1}{2}$ pints of turpentine.
 $1\frac{1}{2}$ „ linseed oil.
 $\frac{1}{4}$ pound of litharge.
 $\frac{1}{2}$ ounce of India red,

Mix well together and use as explained above.

2. *For blue bricks.*

 1 pint of turpentine.
 1 „ linseed oil.
 $\frac{1}{2}$ ounce of litharge,
 1 pound of French ultramarine,

Mix and use as above.

3. *For black bricks.*

 2 ounces of litharge.
 6 „ manganese.
 4 „ linseed oil, boiled.
 6 „ turpentine.

4. *For grey bricks.*

 3 ounces of white lead.
 1 „ litharge.
 1 „ manganese.
 2 „ boiled linseed oil.
 4 „ turpentine.

From these specimens it will be seen that any color may be produced, the fundamental items being the *litharge, turpentine* and *oil.*

Coloring materials could be had in great variety in India, in any bazar almost.

If a brick be dipped in one of the above liquids, and again exposed to a great heat it will become glazed.

These coloring liquids are sometimes used where the brick cannot either be dipped or heated conveniently, as in the case of bricks already built into a wall. In such a case the bricks are carefully cleaned, and the liquid

heated and laid on with a brush. It does not penetrate the brick so well this way, but the color stands the effects of the weather remarkably well.

52. Burning.—The burning of terra cotta goods of all kinds, including ornamental bricks, has to be managed with great care and nicety; but there is one peculiarity in the operation without which the uniformity of color necessary for such goods could not be attained. The goods are completely enclosed in a case of fire brick, or *muffle* as it is called—and the fire is not allowed to come in contact with them in any way.

The accompanying plan of the kiln will show the nature of the arrangement. (*Plate* X).

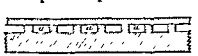
The inner face of the main walls and the muffle are of fire brick, and the muffle, as will be observed, forms a complete shell inside of the kiln. The muffle has a thin arched floor, under which the fires play, and between the walls of the muffle and the walls of the kiln, there are small open spaces left, so as to allow the heat from the furnaces to circulate completely round, and above the muffle. It has an arched top also, and corresponds with the general form of the kiln. The space between the muffle and the walls of the kiln is about four inches, but at the top it is about a foot.

The goods are arranged, rather openly, inside of the muffle, and, in the case of articles that would be likely to get injured from having others placed upon them, it is usual to make slight and temporary pillars of fire brick, as may be required, in the body of the kiln; and on these, broad slabs of the same material are placed for the support of the various articles to be burned.

The whole weight of the goods rests upon the arched floor of the muffle, and as this floor must be thin enough to allow the heat from the furnaces underneath to pass through it readily, and strong enough to support the weight of the goods, the difficulty is met by constructing a series of ribs in the arch, of greater depth than the floor generally. These ribs are at intervals of about 6 inches.

To allow the heat to penetrate as easily as possible, the walls and top of the muffle are constructed of brick-on-edge.

The plan of a portion of the main wall of the kiln and the muffle wall



is like the rough sketch in the margin; and the heat from the furnaces comes up through the spaces marked *a*. The arched roof of the muffle abuts upon the main wall.

The main walls of the kiln are clamped, and held together by strong iron bands. There is one that goes all round it, up near the top, where the arches of the kiln and muffle spring from, and there are upright cast-iron ribs at each corner, connected with iron rods running along the masonry of the main walls. The expansion and contraction of these iron bands cause the walls to crack a good deal, but the iron holds them together, and they would not stand without this support.

The kiln is filled and emptied at the door shown at the back.

When filled, this door—first the muffle and then the main wall—is built up, but there is an earthenware pipe built into the masonry nearly perpendicular to the face of the wall, and through this pipe, the steam from the damp goods escapes during the first three or four days of the firing. It serves also as an opening for observing the state of the goods during the burning, and it is usual to place a few pieces of material to be burned, made into the form of rings near the inner end of the pipe. One of these rings, or *proofs* as they are called, can be drawn out at any time with an iron rod, so as to observe the progress of the burning.* A common black bottle is generally placed also near the *proofs*, and when it melts and sinks down into a shapeless mass, the burning may be considered about done.

When finished, the whole of the furnaces and other openings are carefully closed up and roughly plastered with clay, and the kiln left to cool for a week or so, after which the door may be opened, and the goods taken out when cool enough to be handled.

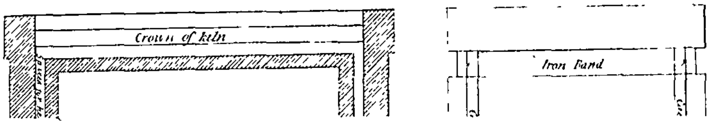
If goods of different colors, such as white clay and red clay, be placed close together in the kiln, they will mutually tinge each other; that is the red goods will receive a tinge of white, and the white ones of red.

53. Moulding.—All terra cotta work and ornamental bricks are moulded in plaster of Paris moulds. The peculiarity of these moulds will be understood from the rough sketch in the margin, which represents a section through the mould.

The outer shell of the mould is represented by the part marked *b*, and there are four separate pieces marked *a*, two side, and two end pieces; c represents the clay of the brick.

The clay is very carefully pressed into the mould with the hand, first

* Any kind of fuel that will burn briskly will answer for the kiln. Both coal and coke are used in England, but wood would do quite well.


Crown of kiln
Iron Band

CHAPTER III.

TILES.

55. TILES are of three kinds—ROOFING-TILES, FLOORING-TILES, AND DRAIN-TILES. Tiles require, if possible, more care in construction than bricks, as from their greater delicacy they are more liable to derangement. The clay should be much stronger than for bricks, very little sand being used, and that only for the very plastic kind. No ashes, chopped straw, saw-dust, or any other foreign substance can be admitted. The best clay will generally be found below the brick soil, and the blue clay is particularly good for tile-making; the same previous preparation of the clay, and the same mode of working and tempering is necessary; and the more effectually to render its state uniform and yielding, so that in moulding it to the various forms required, it may not crack, the pug-mill should be employed, from whence the clay should be removed to sheds under which the moulding is conducted.

Patterns in wood of the exact form of the tiles to be made, should be given to the moulders, as well as forms on and in which they are to mould the tiles, which will of course vary with the kind required, and should be of hard-seasoned wood of the simplest construction, and not liable to warp. These are the more necessary, and their use should be enforced, to prevent a common practice of the natives of sticking on strips of clay to the edges of a flat or sole piece to form the raised sides, which can be broken off by the finger and thumb when burnt. They should be made in one piece by the aid of a mould for the purpose, the edges being either turned up over a square edge, or worked into the sole, and the upper edge trimmed with an iron tool. The drying should be entirely in the shade in the hot weather, as from being thin, the tiles will warp if exposed to the sun; great care should be observed in laying them out to dry, and when set firm, so to arrange them on edge that the air may have access to all their surfaces. A fence should encircle the drying sheds to keep out dogs and stray cattle.

There is not a material in use in India that requires more attention to improve it than the tile. The present almost universal kind, is light, porous, and absorbs water, is subject to be displaced by high wind or birds, and in the attempt to repair one of these biscuit-like tiles, a man in ascent and descent cracks twenty more. They are besides hardly weather-proof, and cannot, except in combination with that combustible and perishable material, grass, reduce the interior of a building to a habitable temperature, whilst their diminutive size renders the use of a bamboo frame necessary *on which to lay them, which being perishable, rots, or is worm* eaten and sinks; the roof then leaks, its timber decays, and the goods contained in the building are damaged. In addition to which, the expense and trouble of their renewal is constant and great. These are surely reasons enough to show the necessity for the manufacture of a better description of material.

56. In most parts of India, three descriptions of roofing tiles are made, viz, the *Pot-tile*, the *Pan-tile* and the *Flat-tile*. There are also *the* S *tile*, and the large kind generally known as *Goodwyn's tile*.

Pot tiles.—The *pot* are termed *Loolfee* (locking), or commonly, *Loolfeedár*, and are either used with other kinds by covering their raised ledges: or the roof is of curved tiles only, locking into each other by having the adjacent rows laid with the convex and the concave sides uppermost, alternately, The same arrangement is better answered by using the S tiles, which, if well made and of a good size, make an excellent water-tight roof. The objection to them is the difficulty of repairing the roof if any get broken. It is also generally difficult to get them made of a proper shape.

Tiles are generally laid in mortar on a frame-work of bamboos and mats. Sometimes they are used over a thatching of grass, but this arrangement is not recommended, as the grass rots, the tiles get displaced, and the roof leaks. Goodwyn's tiles are laid in mortar over a layer of flat square bricks; they have been largely employed in the Punjab barracks, and make an excellent, though somewhat heavy, roof, (the details of which are described in the Second Volume of the Treatise).

The pot-tiles are made on a potter's wheel, and together with the flat tiles, are in India burnt in an open clamp with dried cowdung in the same manner as bricks. Dried cowdung is an excellent fuel for the purpose, much resembling peat, as it gives a strong heat without blazing or burning fiercely.

The larger the tiles can be made the better, as they are then less easily displaced or broken by birds, and as barracks are much frequented by vultures, adjutants, crows and other carnivorous birds, this is a matter of much importance; large tiles are more difficult to make and to burn than small ones, but as they also cover a greater area, they will often, on computation, be found not to be so much dearer as at first they may seem to be, judging only by the price per thousand.

The Pan-tile is in shape similar to the pot-tile, differing from it only in being shorter, heavier, and less curved. As made by the native contractors, it is also of *very inferior material*, but, as *only one* kind of clay is used for both the pot and pan tile, and equal care should be taken in tempering and manipulating it in both cases, an equally good tile, as regards *quality, is obtained by moulding as by turning on the wheel, with* the further advantage of ensuring a uniform size.

57. Tile Manufacture.—In the manufacture of tiles, as in bricks, the quality of the ware depends *chiefly on three particulars, viz., the nature* of the *clay—tempering—*and *burning.* The following is the method as practised by the Madras Sappers at Mercara.

TILE CLAY.—The clay used is of a blackish color and very stiff, generally found underlying the brick-earth, from 5 to 10 feet below the surface of the ground, in the vicinity of paddy or marsh lands. It is stiff enough to require a little sprinkling of the brick loam immediately overlaying it, or else of sand; the proportion of loam to clay varying with the quality of the latter, which experience can alone determine.

The clay is usually *uncallowed* and dug out immediately before the rains, and spread in heaps, in which state it is allowed to remain during the four or five monsoon months, with the view of breaking down the harder and knotty pieces, so as to render them easier worked; but as it is found in England that wet retards the process of weathering, while hot dry weather or frost is beneficial, this practice may be deemed questionable, until some direct experiments have been made to determine its advantage or otherwise.

After the rains cease, the clay is put into tempering pits, about one foot deep, of any convenient area, and the bottom paved with bricks, where it is covered entirely with water for about twenty-four hours, when a little more water is thrown over it. At the expiration of about twelve hours after this, the clay is trodden by men's feet for two or three hours, which completes the first course of tempering. It is then removed into

sheds by the same people who tread it, and is there formed into conical heaps about four feet high. These heaps are cut, or rather pared, down in thin slices from top to bottom with a circular iron cutter (*Plate* XIV., *Fig.* 1), which process is repeated three or more times, until the hard pieces and stones have been broken down and cleared, and the mixture of clay and loam well amalgamated. It is then well worked and kneaded with the feet on hides or boards into a stiff paste, every hard substance which the eye or feet detect being removed, when it is in a fit state for the potter or moulder.

MOULDING.—For making pan-tiles, a gang of three people only is required, viz:—

Temperer (man) 1; moulder (man) 1; Cleaner (boy or woman) 1.

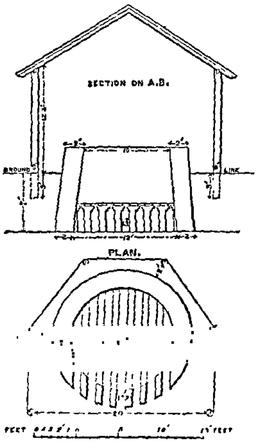
Temperer.—The temperer's duty is simply to prepare the clay in the way above described; for effecting which, all he requires is a *mamoty* or spade, a *chatty* and a basket, and to carry and place the clay in heaps by the side of the moulder. Water is supposed to be sufficiently at hand to allow of the temperer fetching it himself.

Moulder.—The moulder sits on the ground with his *mould* (*Fig.* 2), *water trough* and *strike* (*Fig.* 3) in front, and after covering his mould with wood ashes or finely sifted brick-dust, previously deposited near him, he takes off with his hands a piece of clay more than sufficient to fill the mould, which, after roughly shaping, he throws into the mould with all his force, taking care to work it well into the corners and other parts, and then cuts off the superfluous clay with the bow (*Fig.* 4), made of wire or of string stretched on any elastic piece of wood. He then presses his strike, a flat piece of wood, or ruler 15 inches long, 2 or 3 inches broad, and half an inch thick (*Fig* 3), backwards and forwards over the clay, till the surface is tolerably smooth and level with the upper surface of the mould; after which, opening the thumb and fingers of his left hand, he presses the hand thus extended slightly on to the clay in the mould, which, adhering to the palm and fingers, is easily lifted out and placed on a burnt pan-tile near him. Each succeeding piece thus taken out is placed on the top of the previous one, until a heap of twenty is collected, when a new heap is begun, and so on. The heaps are left till the following day to dry a little,* when the moulder shapes them into the curved form, on the convex

* The time for drying must of course vary with the nature of the climate, and all that is requisite to be careful of on this score is, that the clay is sufficiently plastic to be bent without cracking.

back of a *horse* (*Fig.* 5), by simply bending them gently over it, and smoothing the back of the tile itself with his hand dipt in water. The horse, having been previously well sprinkled with wood ashes or brick-dust, permits the tile to be easily taken off it, which the moulder does with both hands and then places it gently on the ground (which ought to be well rammed and flattened), until one heap of twenty is finished; he then proceeds to another heap, and so on. In this way, an experienced moulder will mould and horse 300 per diem. After lying on the ground five or six hours, or till sufficiently stiff to be handled, the tiles are taken up and re-horsed by a man or boy called the *cleaner or washer-off*.

Cleaner or washer-off.—This individual trims the edges with a knife, clears away the ashes from the interior by rubbing it lightly over with grass, and afterwards washes it with his hand well wetted, rubbing it over till quite smooth. On completing this process, he lays the tile again on the ground where it is left for 8 or 10 hours, until it is *hand-hard*, that is, stiff enough to be placed carefully on its narrowest edge against a board or wall; when they are all picked up and disposed of in this way, that is, standing out at right angles to the wall one over another, and so left until quite ready for burning. In setting the kiln, a flooring is first made by a course of bricks laid flat and somewhat open over the tops of the flues, and on this flooring the tiles are stacked as closely as they will lie on edge, course upon course. When the kiln is full, the doorways* or



* The doorway is not shown; it is merely an opening two or three feet wide in any convenient part of the wall, above ground, for the purpose of filling and unloading the kiln.

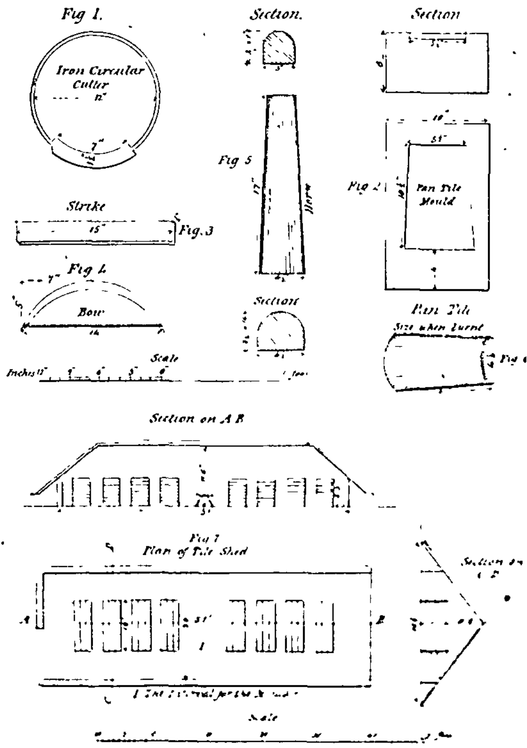


Fig 1.
Iron Circular Cutter
Section.
Section
Fig 5
Fig 2
Pan Tile Mould
Strike
Fig. 3
Fig 4
Bow
Section
Pan Tile
Size when burnt
Scale
Inches
Section on A B
Fig 7
Plan of Tile Shed
Section on C D
A
B
Scale

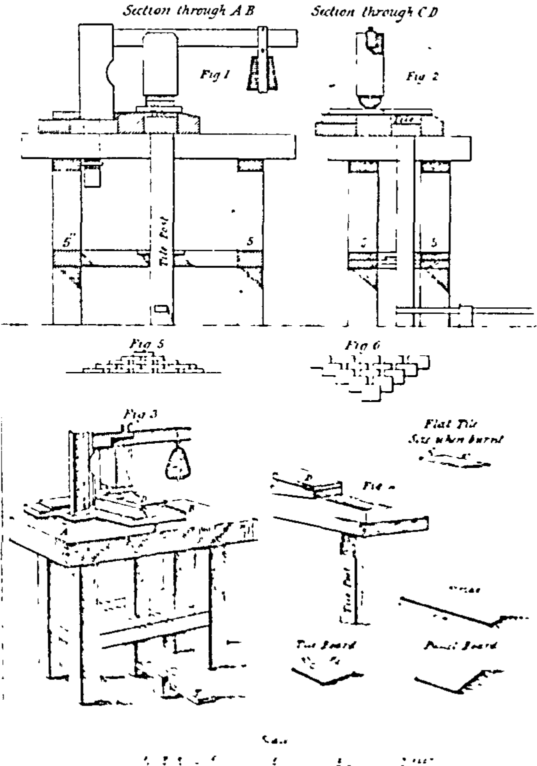
hatches are bricked up, and the top covered with a course of old tiles laid loosely over it.

Sheds.—It is necessary to have sheds, as owing to the stiffness of the clay, the tiles, on exposure to the wind and sun, except for a very short time, crack and get out of shape very extensively. As the natives never go to the expense of constructing such sheds, they are obliged to use a very mild clay to prevent this loss, so that it is no wonder their tiles are of such inferior description.

It is a good plan in order to gain room in these sheds for moulding, to have a series of blocks or drying shelves, which are formed with 3-inch planks, placed $4\frac{1}{2}$ inches one above another, on bricks laid on edge, and carried to any convenient height above the floor. The size of the shed and number of these blocks will depend on the number of moulders at work, but the area allowed to each is 16 feet long, by 20 feet wide, and the moulders should be so arranged as to leave a passage of about 3 feet all around the blocks, so as to have them easily accessible. The moulders sit either in the centre or at the side of the sheds, and the blocks are placed all down the centre (*Fig.* 7.) The blocks should have nine tiers of planking.

Burning.—The burning is effected entirely with wood. The kiln is circular, and of size sufficient to burn 30,000 tiles at a time. As in the case of bricks, the fires must be gentle at first until the disappearance of all white steam; after this, they may be gradually raised to a greater heat, until the inside of the flues appear red hot; the fire is then slackened for six hours, after which, it is again raised till the interior of the flues has been brought to a white heat, and kept so for about three hours. The fire is then again slackened for six hours, putting in no more wood during that time. At the expiration of the six hours, the fire is raised to the same heat as before, and kept up about four hours, when the flues are quite filled with fuel, and their mouths stopped up with brick and mud, the fires being allowed to go gradually out. The burning generally takes 72 hours, being maintained night and day. In windy weather, the kiln should be sheltered as much as possible on the weather side, otherwise, a large number of the tiles on that side will be found underburnt: these are technically termed *burn-overs*, and should be put on the top of the next kiln to be fully burnt.

Cost.—To make a kiln of 30,000 pan-tiles, the following labor and ma-


Section through A B
Section through C D
Fig 1
Fig 2
Tile Post
Fig 5
Fig 6
Fig 3
Flat Tile
Tile Board

taps with the palm of his hand, then turning down the moveable top D, (*Fig.* 4) of the mould on to the clot, he draws the lever and weight forcibly towards him, until it presses hard on the top of the mould, which is effected by three friction rollers fixed into the bottom of the lever post. With his right foot he then gives the treadle T (*Fig.* 3) two or three smart jerks, which tends to press the clay well into all parts of the mould; and afterwards, throws back the lever and weight, raises the top of the mould, and with a wet strike, of the same kind as before described, cuts off the surplus clay; after this, he gently works his wet hand over the top surface of the tile; a pallet board well covered with wood ashes being then placed on the top, the moulder, with one jerk of the treadle, forces out the tile and board on which it rests, ready for the

Bearing-off boy, who stands directly opposite to him, on the other side of the moulding table, and whose duty it is to keep the pallet and tile boards well covered with wood ashes, and to seize and carry off the newly formed tiles, and place them on the blocks to dry. This he does by catching the pallet and tile boards, with the tile between them, gently with both hands; he then reverses the boards by turning them dexterously over, with the tile still between them, thus bringing the tile board uppermost, which, by means of an iron eye fixed in its bottom, he removes easily with his right hand, leaving the tile resting on the pallet board, lying on the palm of his left hand. The tile board he places on the moulding table, ready for the moulder to put in the mould again, and then carries off the tiles to the blocks or in their absence to a *flat*, a piece of ground duly prepared with rammers and *gobar*,* to receive it—here it is left till *hand-hard*, when it is removed by the

Trimmer-off, whose business is to gather up all these *hand-hard* tiles, and place them in heaps of ten or twelve. He then trims the rough edges with a knife, places them one at a time between two flat boards, which he presses together with his hands, and rectifying anything he finds wrong in the shape, he then places them in rows, as in *Fig.* 5, piled one on another, where they are left till quite dry, after which they are carried to the kiln, and stacked as shown.

Burning.—Kilning and burning, being precisely the same as for pantiles, need no description; only it may be observed that the flat-tiles being of smaller dimensions ($6\frac{1}{2} \times 5\frac{1}{2} \times \frac{5}{8}$ inches), the kiln previously described

* Cow-dung, diluted with water.

will hold 50,000 of them; both kinds of tiles, however, are generally burnt together in the same kiln, pan-tiles at bottom and flat-tiles at top.

An experienced moulder with his assistants will mould 500 per diem.

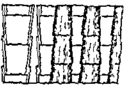
Cost.—The cost of labor, &c., for 50,000 flat-tiles is as follows:—

	R.	A.	P.
[illegible]	1	7	0
[illegible]	12	8	0
[illegible]	25	0	0
[illegible]	8	6	4
[illegible]	8	6	4
[illegible]	8	5	4
[illegible]	3	2	0
[illegible]	13	8	0
Burning, 18 men, at 2 annas,	2	4	0
Total,	82	13	0

The cost in this instance, as in pan-tiles, is exclusive of kiln, sheds, and tools.

It is, perhaps, scarcely necessary to observe that sheds for moulding and drying are equally required in this case, as for pan-tile making—these need no description.

59. **Goodwyn's Tile** is a large and substantial flat-tile, with raised edges, the joints between which are covered with a semi-cylindrical tile, precisely such as were in use by the Romans.



Atkinson's Tiles are similar to Goodwyn's, and the method of roofing with both of them is described in Vol. II., in the Section on Buildings.

Syrian Tiles are used in arched roofing, and the method of using them is described in the Section on Masonry. They are turned on the potter's wheel, and are hollow like ordinary flower pots, but closed at top and bottom, and slightly flattened at the sides like flat stone bottles. They are generally about 9 inches high, with a larger diameter of 5 inches, the smaller depending on the curve of the roof.

60. **Sindh Tiles.**—An improvement on this kind of tile, called the *Sindh Tile*, has been lately introduced by Lieut.-Colonel Fife, R.E., and used with much success in Sindh. The following account of their manufacture is taken from Vol. I., of the "Indian Professional Papers." The mode of roofing with them is described in a subsequent chapter of the "Masonry" Section.

* A cubic yard of clay well rammed and tempered will make 2,180 flat-tiles, $5\frac{3}{4} \times 6\frac{3}{4} \times \frac{3}{4}$ inches.

Description of the Method of Making Hollow Hexagonal Voussoirs for Vaulted Roofs.—A solid wooden voussoir is first made in the following manner:—A piece of wood about 15 inches in length and 9 inches in diameter, is shaped into a tolerably accurate cylinder. Its ends are then sloped off, till it becomes oblique, as shown in *Fig.* 1. Hexagons are then inscribed in circles of about 8 inches diameter, at each end, (*Figs.* 2 and 3,) care being taken, by previously drawing a straight line from top to bottom of the cylinder, to make the hexagons parallel. From the sides of the hexagon at the bottom, half an inch or whatever may be required, is cut off (*Fig.* 3). The superfluous wood is then pared away, leaving the solid hexagonal voussoir, as shown in *Figs.* 4 and 5, a piece of wood being inserted at the broad end as a handle: at the other (narrow) end, a small hole, about 1 inch deep is bored at the centre.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

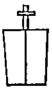
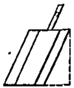
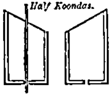


Fig. 5.



Some common earthern *koondas* (cylindrical pots) of the section shown in (*Fig.* 6,) are then made, in the ordinary manner, having their tops sloped at the same angle as the voussoir, (but accuracy in this case is not necessary.) When the koondas are dry, they are sawn in two; after this they may be burnt. They may also be made of wood; but the earthen ones only cost a few annas each, and are not liable to warp.

Fig. 6.



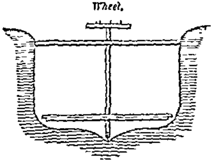
To make the moulds, clay mixed the day previous, and containing rice bhoosa, to prevent cracking, is beaten into flat cakes with the hand, and placed in the half koondas, and well pressed against the sides and bottom with the hand. The two pieces of koonda are then bound together with a piece of rope, and placed upon a levelled piece of *soft* ground. An iron rod, something less than a quarter of an inch in diameter, is then inserted into a hole at the centre of the bottom of the koonda. Next, the wooden voussoir, (which as above stated, has a small hole bored in it for the reception of the rod which working through the central hole at the bottom keeps the axes of wooden voussoir and of koonda truly coincident, so as to insure uniform thickness in the sides of the mould under construction,)

is forced into the koonda, pressing the clay against the sides and bottom, and forcing down the iron rod into the soft soil below. This is repeated four or five times, care being taken to keep the voussoir wet, to prevent it adhering to the clay. If there appears to be too little clay in the koonda, from the cakes having been too thin, more can be added, until the wooden voussoir, by compressing it, forms a mould as accurate as itself. The voussoir ought to be carefully withdrawn from the mould, otherwise the mouth will be spoiled.

The mould ought not to be removed from the koonda for four or five days, as the mass of clay being great, it is liable to crack; it ought, moreover, to be kept in the shade, and while drying, any cracks that may appear ought to be stopped with moist clay. As the moulds are removed from the koondas, the weight may be greatly reduced by taking an adze, and paring the exterior into the form of a hexagon, corresponding with the inside of the mould. When they are dry, holes should be made in the bottom, to correspond with the tenons on the wheel (*Fig.* 7) on which the hollow voussoirs are formed. By doing this before the burning, much labor is saved, the dry clay being easily cut with a chisel. The moulds may then be burnt. Litter is the best fuel for this purpose, wood creating too great a heat, and causing them to lose their shape from fusion.

Fig. 7.

Wheel.



To make the hollow voussoirs, the clay used should be what is commonly called "strong earth," or what is used for pottery. It should be beaten into dust, and then mixed with dry horse-dung, also beaten to dust. Water should then be added. An hour or two afterwards, when the clay is completely saturated, it should be well mixed with the hand, sufficient water being added to make it of the consistency of paste or putty, so that it can be taken up in the hand and easily compressed into any form. It should remain in this state for twenty-four hours, after which it is fit for use.

The mould is filled in the same manner as the koonda. A piece of clay, taken from that before-mentioned, is well worked up with the hands on a piece of plank, in the same way in which a native makes his bread. It is then beaten out with the palm of the hand into two flat cakes, which are carefully placed against opposite sides of the mould, and overlapping

each other a little. The clay should then be well pressed into all the angles of the mould with the knuckles. After this, a piece of clay, about the size of an apple, should be thrown smartly to the bottom of the mould. If this is well done, it drives the clay previously placed most effectually into the acute angle at the bottom. The pressure of the knuckles is not sufficient there; and, moreover this last piece of clay makes the circular wedge or mandrill act more effectually. The mould is then placed on the wheel, and a small chip of wood (*a*, *Fig.* 8), an eighth of an inch thick, inserted between the clay and the lower side of the mould. This is to prevent the wedge from making that side of the voussoir too thin. There is no necessity for a similar precaution for the other sides. An iron rod like that previously mentioned, is then passed through the bottom of the mould into the top of the wheel. Next a circular wedge or mandrill about half an inch less in diameter than the breadth of the mould, so as to leave round it about a quarter of an inch of clay for the thickness of the voussoir, and having a hole bored through it for the rod, is placed in the mould, and plenty of water sprinkled on it. The wheel, with the mould on it, is then set in motion with the foot, the wedge being thoroughly held with the hands and gently pressed downwards.

Fig. 8.

Section of Mould and Circular Wedge.

If it descends very rapidly, it will be found on taking it out, that the cakes of clay are too thin; whenever this appears to be the case, more must be added with the hand. If the wedge does not descend to the bottom, it is owing to there being too much clay, and this will have accumulated under it. This should be removed, care being taken in doing so not to tear the sides of the voussoir. The hand should be conveniently placed against the clay, and the wheel set gently in motion. The surplus clay is neatly cut off in this manner. The wedge should then be again inserted, and the process continued, till the inside of the voussoir is perfectly smooth and free from flaws. The wedge should be slowly removed from the mould, the wheel being kept in motion. The wedge ought to go to the bottom of the mould. This is ascertained by looking at the indentation made in the clay by the projecting piece, *b*, at the bottom, and which is made to prevent the wedge descending too far and destroying the bottom of the voussoir. It will be observed, from the manner in which the voussoir has been made, that the acute angle at the

bottom is solid. This must be scooped out with the hand; and, at the same time, the water which collects there during the process above described, should be removed with a piece of cloth.

The next process is the closing of the mouth. The surplus clay and chip of wood are first removed. A good piece of clay, tolerably stiff, is then rolled between the hands, until it is almost a foot long and an inch in diameter. One end of this is attached to the mouth of the voussoir, and the wheel being set gently in motion, it is carried all round, and well joined to the voussoir, by pressing it and the side together with the thumb and the fingers. This effected, the projecting clay is lightly held between the thumb and the fingers, and the wheel being kept in motion, the mouth is gradually closed. If there is not sufficient clay, a small cake about the size of a rupee should be gently placed on the aperture, and the escape of the air inside immediately stopped by adding water, and joining the cake to the clay previously placed. If this is not done quickly, the mouth will sink.

The mould containing the voussoir may then be placed in the sun to dry, and when the clay begins to stiffen, the mouth must be hammered flat, a small hole being made to allow the air to escape. In three or four hours the voussoir is sufficiently dry for removal from the mould; the mould being turned upside down, the voussoir drops out.

In four or five days the voussoirs are dry enough for burning. This is done in the same way as with common pottery. A layer of dry sheep's dung is first laid on the ground, and over this a layer of light litter. On this bed two layers of voussoirs are placed, and over the whole is another layer of litter, covered with ashes. The ashes prevent the flame from escaping too soon.

	RS.	A.	P.
One coolie,* with two assistants to fill the mould for him, will, after a month's practice, make 70 voussoirs per day. Allowing the first, in consideration of his skill, ...	0	2	6
And paying the assistants at the usual rate (viz., 2 annas each),	0	4	0
We have ...	0	6	6

for the cost of making 70, or say 10 annas per 100.

Again, one *buttee* maker, assisted by two coolies, will prepare a buttee containing 700 voussoirs in a day. Allowing the buttee maker for his work, and for watching the buttee during the night, ...	0	5	0

* These were the prices in 1851.

	RS.	A.	P.
Paying the assistants at the usual rate of two annas each, ...	0	4	0
And allowing one cart and a coolie, 8 annas per day for two days for collecting litter, ...	1	0	0
We have ...	1	9	0

for the cost of burning 700, or say 4 annas per 100. Adding this to the cost of making, we have 14 annas for the cost of making and burning 100 voussoirs.

61. **Flooring-tiles** are made like large flat-bricks from 1 to 2 inches thick, and generally 12 inches square. When laid carefully in cement they make an excellent floor, more economical and durable than the ordinary terrace work, especially in a barrack. They should be more carefully made than common bricks, as they have to stand the wear and tear of feet.

62. **Colored tiles** of various patterns have lately been much employed for floors in England, and it is astonishing that scarcely an attempt has been made to introduce them into India, where they would make an excellent, cool, and clean floor, for public or private buildings. Excellent glazed tiles are made at Mooltan and Peshawur, in blue and white; and hexagonal tiles of these two colors look very well when laid down alternately. The glaze used is made from borax. The coloring matter is cobalt *(lajwurd)*, for the Blue color, Green is also produced from copper; and Yellow by employing lead. Patterns cut in relief in wood can be stamped in the tile when soft, and the hollows filled in with the coloring matter. In a somewhat similar manner the encaustic tiles used in England are produced, and there seems no reason that they should not be made in this country, either with or without a glaze.

The best known encaustic tiles of England, are those made under patent by Messrs Minton and Co, who have overcome the difficulty of getting clays of different colors to amalgamate in such a way as to shrink equally during the processes of drying and firing. Minton's tiles are yearly becoming more appreciated, both on score of durability and ornament. His colored "tesseræ" for Mosaic pavements are beginning now to be used in India, and some of the Bombay public buildings are floored with this material.

To attempt the best kinds of ornamental glazed tiles would be out of place in the present state of such knowledge in India, but there seems no reason, why a fair description of tile, with pattern, but unglazed, might not be produced.

Such tiles are made in England simply enough.

A tile is made of say, good red clay, with a portion of glass and crockery, and a pattern stamped into it to a depth of about a quarter of an inch.

Then lay on the stamped surface a coat of the following mixture with a brush—

1 of clay 2 of ground flint or glass, $\frac{1}{4}$ of dry white lead,	mixed with water.

This will prevent the different colors from running into each other.

Now, the several parts of the pattern may be filled in with clays prepared and colored as may be required, and when properly finished in this way, the tile is dried and burned.

The stamp for such a pattern is made from plaster of Paris.

The general rules as to making and burning as given before for "Colored bricks" are applicable also to colored tiles (*v. pages* 79 *and* 80).

Under the head of flooring tiles, may be mentioned an excellent kind of flooring brick in use for stores and such places; and which appears to be remarkably well suited for barrack floors, and similar purposes in India. It is made from ground clinkers, vitrified bricks, and such materials, mixed with a portion of good cement.

The clinkers, &c., are ground to a rough state only, and when well mixed with the cement, the material is moulded and left to set, not burned.*

63. Drain tiles belong to the coarsest class of earthenware. They are of various shapes, and are made in various ways. Some are moulded flat and afterwards bent round a wooden core to the proper shape. Others are made at once of a curved form, by forcing the clay through the mould by mechanical means. Tile-making machines are now almost universally superseding manual labor in this manufacture, and many machines of various degrees of merit have been patented during the last few years.

If intended to carry off sewage, it is essential that they should be glazed, so as to prevent their absorbing the foul matter.

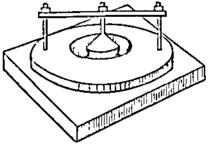
The simplest form of glazing is that used for the common "Delft ware" of Holland. In the Dutch manufactories whenever any of the tiles are to be glazed, they are varnished after they are baked; the glaze being put on, they are put in a potter's oven till the composition begins to run. The glaze is generally made from what are called lead ashes, being lead

* Bricks of this kind are very hard and heavy, and wear remarkably well under heavy traffic.

melted and stirred with a ladle till it is reduced to ash or dross, which is then sifted, and the refuse ground on a stone, and re-sifted. This is mixed with pounded calcined flints. A glaze of manganese is also sometimes employed, which gives a smoke brown color. Other colored glazes are used, in somewhat the same manner as described on pages 79 and 80 in regard to colored bricks. Iron filings produce black, copper slag, green; smalt, blue. The tile being wetted the composition is laid on from a sieve.

64. **Irrigation Pipes.**—In the Upper Provinces, great improvements have been lately effected in the manufacture of earthen-ware pipes, which are now extensively used as irrigation outlets *(colabas)* on the canals, in place of the old wooden tubes; and the following account of their manufacture, near Allygurh, by Captain Jeffreys, R.E., will be found interesting and useful. The tiles so turned out are strong, durable and economical, and almost, if not quite, impervious to moisture. If glazed they would answer admirably for sewage or drainage purposes.

Earthenware pipe manufacture at Nanou, in the Allygurh Division, Ganges Canal.—The moulding machine consists of a strong wooden vertical cylinder, 5 feet 6 inches in length by 20 inches in diameter, supported on beams firmly embedded in masonry. It is constructed of well seasoned seesum, 3 inches in thickness, secured on the outside with four iron bands, $\frac{1}{2}$-inch in thickness. In the cylinder is a piston worked by a wooden screw, 8 inches in diameter, and at the lower end is inserted a dod or die of the following shape.



The clay, after being previously prepared and worked up to the required consistency, is thrown into the cylinder, and pressed out of the dod by the action of the screw. The clay as it escapes is evidently moulded into the form of a pipe.

Below the die is a moveable platform balanced by means of weights attached to ropes running over pulleys, and arranged in such a manner that the resistance offered should just be overcome by the descending clay. When the necessary length of pipe is attained, the action of the screw is stopped; the pipe is cut off with a piece of thin wire, and removed to the drying sheds. Being

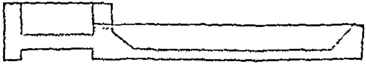
relieved from the pressure of the clay, the platform ascends to its former position, and the operation is repeated. The cylinder full of clay contains twelve 8-inch pipes. In this manner 250 to 300 can be taken out in one day.

The pipes are then kept from four to five days under sheds to dry; if exposed to the sun or wind, they crack or lose their shape.

Appended is a sketch of the furnace used for burning the pipes. It has six arched flues radiating from one centre, enclosed under a conical shaped dome, 18 feet in diameter; it is supplied with four air holes at top and six fire holes below, as well as two doors. The pipes are stacked in an upright position as closely as they will lie, one course above another, and as the body of the kiln is filled, the doorways are built up with kucha or refuse bricks.

From continued experiments made at Nanou, it was found that it required 36 to 48 hours to burn the pipes thoroughly. The tiles are gradually brought up to a red heat and maintained so for 12 hours; after which the kiln is raised to the greatest heat possible, that is, until the flame and the pipes are of the same color and this is kept up for 24 hours. The kiln is then allowed gradually to cool, the admission of cold air being carefully guarded against. In the N. W. Provinces the fuel best adapted and most easily procurable is dry babool wood; but where coal can be obtained at a moderate cost, it would no doubt be preferable.

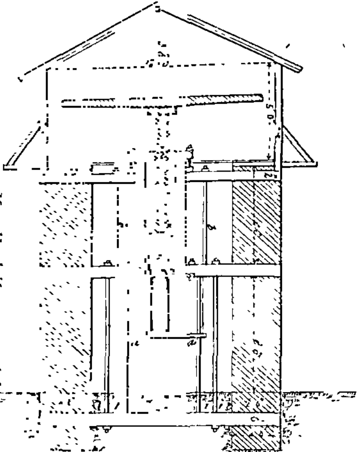
Great care should be taken in the preparation of the clay, as any particles of stone or kunkur left in the clay, are liable to stick in the die and score the surface of the pipe. The most efficient and least expensive method of removing all foreign particles and rendering the clay fit for use is the *blunging* process. It was found most successful, and gave a fineness of texture to the ware which is quite unattainable by pugging or any other method. Two sets of masonry tanks, one raised 2 feet above the other,



were constructed, the upper communicating with the lower by means of pipes built into the masonry, 2 inches above the flooring of the former.

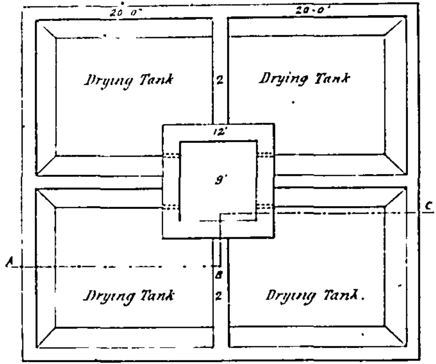
MANUFACTURE OF IRRIGATION PIPES.

Section of Tile-Making Machine and House



a a Moveable platform suspended from Stringers b.b.

PLAN



Section on A B C.

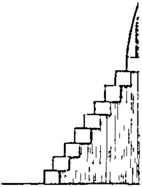
and by using fire-clay cement instead of ordinary clay, there will be little fear of the arches giving way, at the greatest heat to which the furnace will be subjected.

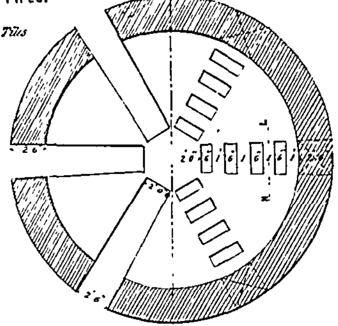
The tiles were made without sockets, as it was found they were not actually required, the joints being rendered perfectly water-tight by embedding them in lime. Sockets can be moulded on the tiles by hand, before they are completely dried, and would prove of use in keeping the pipes in their respective places and preventing them from slipping, but in any case the lime must chiefly be depended on for a perfectly water-tight joint.

The great superiority of the pipes manufactured at Nanon over those turned out of ordinary tile making machines, consists in the pressure to which the clay is subjected during the process. When using firm clay (not over moist), it was found that the piston descended one-third of the depth of the cylinder before any clay escaped from the die, showing that the clay was compressed into two-thirds of its ordinary density. The united exertions of 8 men were required to force the clay out of the die, producing a pressure on the clay of nearly 10 tons.

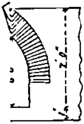
ON PIPES.

ng Tiles

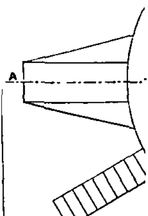


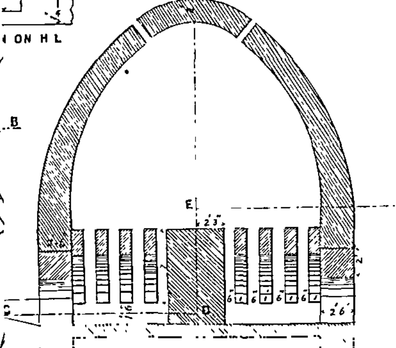


SECTION ON C.D.E.F.



ON H L





SECTION ON A B

CHAPTER IV.

LIMES, CEMENTS, MORTARS, CONCRETES AND PLASTERS.

65. All calcareous cements have lime (oxide of calcium) as their basis mixed with various other materials in different proportions. Lime is most usually found combined either with carbonic acid, in which state it forms a considerable portion of the earth's crust; or with sulphuric acid, when it is called *gypsum*. The cement formed of gypsum, termed Plaster of Paris, has hitherto been seldom used in architecture, except for ornamental purposes, protected from the weather.

Carbonate of lime is found either pure, that is, consisting of 436 parts carbonic acid to 564 of lime; or, mixed with alumina, silica, magnesia, oxide of iron, &c., in varying proportions. White chalk* and Carrara marble are specimens of the purest carbonate of lime; lias lime, kunkur, and many other limestones may be cited as specimens of the impure carbonate.

66. If a piece of carbonate of lime be calcined, the carbonic acid will be driven off in the process, and the cohesion of its particles will be so much lessened, that granular limestone, if very pure, will fall to powder in the kiln wherein it is burnt. The lime after calcination becomes quite white or light brown, whatever was its former color. In this state it has lost its affinity for carbonic acid, and is termed *caustic* or *quick lime.*

Quick lime, on being mixed freely with its equivalent of water,† *slakes*, that is, throws out great heat, swells, and assumes the form of a fine white powder. This is *hydrate of lime*, in which state the affinity for carbonic acid is restored; but though at first it quickly absorbs carbonic acid from the air, the process gradually becomes slower, and it has never been found to have recovered its full equivalent. Lime, in recombining with carbonic acid, parts with the water it combined with in forming a hydrate.

To form a cement with hydrate of lime, it must be mixed with suf-

* All the colored chalks, termed gray chalks, which are the lower chalks of the geologist, possess more or less, hydraulic properties.

† *The equivalent* of water is the amount of water which, on mixture, the lime will take into intimate combination with itself. 3·56 parts of lime combine in this way with 1·125 of water, which, therefore, is the minimum quantity required for slaking

ficient water to form a paste of the consistency required. After having been applied as a cement in this plastic form, in order that it may *set* or recover its original hardness when in the form of a carbonate, it would seem necessary only to subject it to pressure, and in some cases give to it access to the carbonic acid of the air.

67. Lime is besides usually mixed with sand, gravel, or some such extraneous matter previous to use; and their mixture, when formed into a paste with water, is termed *mortar*.

The distinction between the mortars made of pure, and those made of impure carbonates of lime, consists in this, that the former have in themselves no property which can produce setting without the presence of carbonic acid; that is, practically, without exposure to the air. Mortars made from impure carbonates, on the other hand, contain within themselves to a greater or less degree this property of solidifying without the assistance of the atmosphere. From this property, which enables them to harden under water, they are called "*hydraulic limes*," or "*hydraulic cements*."

As pure lime mortar must combine with carbonic acid, that it may harden or set, and as, in this combination, it must part with the water contained in it, it follows that hydrate of pure lime in a state of paste, if kept moist, will remain for an indefinite period without absorption of carbonic acid, whilst if exposed to the dry air without pressure, the small quantity of carbonic acid gas is gradually absorbed from the atmosphere; but the lime assumes the form of powdered chalk or marble, which is wholly useless as a cement, no longer forming paste with water. It follows, therefore, first;—That pure lime mortar is badly adapted for cementing thin walls above ground, where the action of the air will dry it, and reduce it to a powder before a sufficient pressure can be brought to bear on it; and, secondly;—That it is utterly unadapted for situations like the foundations of a building, or the heart of any heavy masonry, where it is protected from the action of the carbonic acid gas from the atmosphere, and is frequently exposed to damp, so that no solidification can ensue.

It is evident, then, that for all buildings having any pretensions to importance, it is advisable to use mortar made from hydraulic lime, and where this is not to be found in a natural state, to try to produce it artificially by mixing with the carbonate of lime the ingredients which are wanting to give it hydraulic properties.

68. The mode of occurrence in nature of calcareous substances, as of any other minerals, is only intelligible through the principles of Geology; for which the student is referred elsewhere. A few guiding remarks are all that it will be necessary to give here.

The varieties of limestone that are perhaps, most used in India for building purposes, are calcareous *tufa*, limestone boulders, and *kunkur*. Tufa is formed by the solution of limestone by carbonated waters and its deposition by evaporation at the surface. For this process, a surface, more or less decidedly undulating, is implied. Whenever this condition is met with, together with the presence of a calcareous rock (itself in most cases unserviceable as a source of lime), tufa may be confidently sought for. These conditions exist in most hilly districts; for it is the exception when any extensive mass of rocks is entirely devoid of calcareous matter in some shape; and this becomes collected and concentrated in the manner described. Lime thus obtained is extensively used in the districts bordering the hills on the north and south of the Gangetic plains. Tufa being essentially a local deposit, its extent must be carefully estimated before much reliance can be placed on it. This stone is admirably adapted for native use; from its porous texture it is easily broken, and easily burned, and it yields its full proportion of pure white lime, the qualities of which, when moderate care has been used, can be depended upon.

Most of the torrents from the Sewaliks and outer Himalayan ranges yield an annual crop of limestone boulders, which are extensively used for lime, as they require no quarrying. The chief objection to lime from such a source, is its uncertain quality if nicety be required. This difficulty was experienced at Roorkee in an attempt made by the late Captain E. Fraser, R.E., to make a quick setting cement for rapid repairs in the Ganges Canal Works. Some of the samples of the lime with which it was proposed to operate (a boulder lime from the Sewaliks) exhibited to analysis a difference of composition of as much as twenty per cent. The reason is evident. In a small basketful of the pebbles, one may find a dozen different varieties of stone from as many different beds of the anciently denuded rocks of the Himalayas.

Kunkur is a variety of limestone extensively used for lime, and most abundantly found in the great plains of India. Colonel Sir P. T. Cautley, has noticed the frequent occurrence of kunkur deposits in the vicinity of jheels, or where jheels may formerly have existed; and it has also been fre-

ings and decanted fluid are now mixed, and ammonia added until the solution smells of it; and then solution of phosphate of sodium; the whole is then well stirred. If the stirring is kept up for 15 or 20 minutes, the whole of the magnesia will be thrown down as magnesium and ammonium phosphate, which may be at once collected on a filter and washed with cold water, having about $\frac{1}{10}$ of solution of ammonia added.

9. The insoluble residue obtained by process in para. 4, is now, having been dried, incinerated along with the filter and weighed; a certain amount is deducted for filter ash; this amount is ascertained by incinerating 10 filters, and dividing the ash obtained by 10. The weight of the residue is now calculated as a percentage result, and entered in the analysis as residue insoluble in hydrochloric acid or simply siliceous residue. It contains any sand, clay, and organic matter which may be in the sample.

10. In the case of a hydraulic limestone, the clay in this insoluble residue ought to be estimated: for this purpose, it should be thrown little by little into a boiling solution of carbonate of soda (best boiled in a silver vessel). The pure silica or sand will be thus dissolved, and the clay left insoluble; it is only needful to ascertain the weight of the latter after thorough washing, drying and incineration.

11. The precipitate of oxide of iron and alumina obtained in para. 5, is now incinerated and weighed, and (after deduction for filter ash) calculated as a percentage, and entered in the analysis as oxide of iron, and alumina dissolved by hydrochloric acid.

12. The precipitate of magnesia and ammonium phosphate obtained by para. 8, is also dried, incinerated and weighed, and the amount multiplied by 2, as only half the filtrate was used. (it should be well dried before incineration,) filter ash being deducted. Every 222 parts of the substance weighed contains 80 of magnesia, its composition being the magnesium pyrophosphate $Mg_2P_2O_7$.

13. *Estimation of Carbonic acid.* In the case of a limestone, it is not needful to estimate the carbonic acid, as all the lime, and all the magnesia obtained in the analysis may be calculated as carbonates and entered in the analysis as such. Every 56 of lime, and every 40 of magnesia require each 44 of carbonic acid. In the case of a mortar, the carbonic acid must be determined as part of the lime exists as hydrate and part as carbonate. About 3 grammes of the finely pounded mortar are put in a small flask fitted with a chloride of calcium tube, and a very small test

tube: in the latter is put some strong hydrochloric acid. The mortar at bottom of flask is covered with distilled water, the small test tube full of acid is lowered in by means of a piece of fine platinum wire, so as to remain upright, and allow no part of its contents to be spilled. The chloride of calcium tube fitted to a cork with a small draught tube, is then adjusted to the mouth of the flask, and the whole is weighed. Then the flask is inclined so as to spill the hydrochloric acid among the water and mortar (the acid should only be spilled over gradually;) a brisk effervescence ensues from the escape of the carbonic acid; when all the acid has been spilled over, and effervescence has quite ceased, a gentle draught of air is drawn through the apparatus by the mouth; the apparatus being now weighed, it will weigh less; the loss shows the amount of carbonic acid.

71. The following is given, by Sir C. Pasley, as a simple practical mode of testing a stone supposed to contain *hydraulic* lime or cement :— The stone ought to be bluish gray, brown, or of some darkish color, as white indicates pure limestone or gypsum. On being touched by the tongue, the presence of clay ought to be quite perceptible to the taste. It should also be detected by its smell after wetting. It should only partially dissolve in diluted acid,* leaving a more copious sediment than pure limestone. This may be considered the first chemical test. Should this test be satisfactory, break the stone into fragments not exceeding one and a half inches thick, and put a few of these into an ordinary fire-place, (first heating them gradually, that they may not break into too many small pieces), and keep them to a full red heat for about three hours. Take out one of the fragments, and put it into a glass of diluted hydrochloric acid. Should the stone be just sufficiently calcined, no effervescence will take place, and its original color will remain unchanged; any effervescence showing that the stone is not sufficiently burned. On the other hand, should the stone be overburned, on taking it out of the fire, it will be of a darker color than before. Having obtained a piece properly calcined, pound it to an impalpable powder; being *very* careful not to allow any grittiness to remain. Mix this powder with a moderate quantity of water, by means of a spatula or strong knife, on a slate or slab, and knead it into a ball between the hands. It will soon become warm; and, if it be a good hydraulic cement, it will not only harden in the heating, but, if put into

* Hydrochloric acid is the test. In its absence nitric acid, or even vinegar, may be used, according to M. Berthier.

a basin of water, it will continue hard, and go on hardening. It is better not to put it into water, until it shall have begun to cool a little.

The proper proportion of water is between one-fourth and one-half; the addition of a larger quantity making a very thin paste, which will take much longer to set, although ultimately the slow setting ball will become as hard as the others. A great excess of water will, however, destroy the cement. The balls should be allowed to remain in a basin of water for a long time, taking one of them out at intervals of ten days for a month or two, and noting the hardness of their interiors. As a saturated solution of lime-water would be very soon formed in the basin, the water should be changed daily, in order to ascertain the full value of the cement.

72. Limes Classified. *For practical purposes, Vicat's division of limes, which, although not absolutely, is still approximately, correct, may be well adopted, as follows:—*

1st.—Fat, or common *lime, which gains no consistency under water,* remaining in a state of paste in water unchanged, but dissolving wholly in pure water frequently changed.

2nd.—Poor lime, which is a combination of lime and sand,* the lime in which exhibits the same phenomena, as if no sand were present.

3rd.—Slightly hydraulic limes, obtained from limestone containing eight to twelve per cent. in all, of silica, alumina, magnesia, iron, and manganese. These set in about twenty days after immersion, but in a year have not *gained a consistency greater than hard soap. They dissolve in pure water,* but very slowly.

4th.—Hydraulic limes, from limestones containing from twelve to twenty per cent. of the above-mentioned ingredients; these set in from six to eight days, and in six months acquire the hardness of soft stone.

5th.—Eminently hydraulic limes, from limestones containing twenty to thirty per cent. of the same ingredients; they set in from two to four days, and have attained great hardness in a single month. In six months they resemble the absorbent calcareous stones which bear cutting. They splinter under a blow, and present a slaty fracture.

6th.—Hydraulic cements, from stones containing thirty to fifty per cent. of argil; these set in a few minutes, and attain the hardness of stone in the first month.

* Although sand is essentially "silica," still silica in this form confers no hydraulic properties! To do so, it must be in close combination with alumina.

73. Hydraulic Cements.—The term Hydraulic *Cement* is generally used in distinction to Hydraulic *lime*. The former, containing a large proportion of silica and alumina, and a smaller proportion of carbonate of lime than the latter, does not slake, and sets generally in a few minutes even under water. Hydraulic limes on the other hand, slake thoroughly and harden slowly under water. Some limestones exist which, when completely calcined, yield hydraulic lime; but when imperfectly calcined, yield cement. Other limestones, such as chalk, when imperfectly calcined, or too much calcined, yield fairly hydraulic limes; while, if they be calcined merely up to the point where all the carbonic acid is driven off, and no further, they yield a lime which never solidifies under water. Other limestones yield on calcination a result which can neither be termed lime nor cement, owing to its slaking very imperfectly, and not retaining the hardness which it quickly takes when first placed under water.

74. *Roman Cement.* The natural hydraulic cement, best known in England, is that which is termed "Roman," or, "Parker's Cement." The stone is found in the form of nodules in the island of Sheppey and elsewhere in the London clay. The composition of these nodules is almost the same as that of the Boulogne pebbles, from which a similar cement is made. Before being burnt, the stone is of a fine close grain, of a rather pasty appearance; the surfaces of fractures being greasy to the touch. It sticks easily to the tongue; its dust, when scraped with the point of a knife, is a grayish white. During the calcination, the stone loses about one-third of its weight, and the color becomes of a brown tinge, differing with the stones from which the cement is made. It becomes soft to the touch, and leaves upon the fingers a very fine dust; it sticks very decidedly to the tongue. When taken out of the kiln, it absorbs water with much difficulty. It is usually burnt in conical kilns, to an extent sufficient to drive off the carbonic acid, and it is then pulverized by the manufacturer; and sold in well closed casks. In Russia, America, India, and elsewhere, similar natural cements have been met with;* but, as they are comparatively rare and expensive, much attention has been bestowed on finding or inventing a substitute for them.

75. *Pasley's Cement.* Vicat was the first to point out the method of forming an artificial hydraulic cement by the mixture of lime and unburnt

* Carbonate of magnesia alone has been found to yield, on calcination, an excellent hydraulic cement. When mixed with one and a half times its bulk of sand, it makes a beautiful hard plaster or stucco.

clay; and General Pasley afterwards, in a most elaborate series of experiments, proved that a hydraulic cement might be formed equal to the best obtained from natural sources. General Pasley's experiments were made principally with chalk lime, and the blue alluvial clay of the river Medway, near Chatham. The result he arrived at was, that a mixture of 4 parts by weight of pure chalk perfectly dry, with 5·5 parts, also by weight, of alluvial clay, fresh from the Medway, or of 10 parts of the former with 13¾ of the latter, would produce the strongest artificial cement that could be made by any combination of these two ingredients. The weight of the blue clay be found to be ninety pounds, and of the dry chalk powder forty pounds, per cubic foot.

His method of proceeding was as follows:—The clay was weighed when fresh from the river (taken from about eighteen inches below the surface), and was never dug unless required at once; it being found that even twenty four hours exposure to the atmosphere injured it. The chalk was not weighed until well dried and pounded, owing to its extraordinary retentiveness of moisture. The chalk was then mixed with water into a thick paste. The chalk and clay were then each separately divided into portions or lumps as nearly as possible equal, and put alternately into a pug-mill of the ordinary description, where they were most thoroughly and intimately mixed. The raw cement thus formed was then made up into balls of about two and a half inches in diameter, and placed in the kiln alternately with about equal layers of fuel—a layer of fuel always being at the top and bottom. The fuel used was coke, in preference to coal; and, in the small furnace or kiln used by Sir C. Pasley, three hours was found to be about the average time required for burning the cement. As the calcined cement was drawn from the bottom of the kiln, fresh cement could be put in at the top. The balls, on being raked out, could be tested by applying to them diluted hydrochloric acid. If sufficiently burned, no effervescence ensued; but if they effervesced, they were put into the top of the kiln again to be reburnt. (*See* para. 71). The calcined cement balls, since they would not slake like ordinary lime, were then ground to impalpable powder,* and stored for use, so that they should not be exposed to the atmosphere. The average out-turn was about nine and a half measures of calcined, out of ten measures of raw, cement.

* The method usually adopted in practice for grinding hydraulic cement is first to break the burnt stones into small fragments, either under iron cylinders or in mills suitably formed for this purpose, and then to grind the fragments between a pair of stones, or to crush them under an iron roller.

Where only hard limestone is to be obtained, General Pasley suggests that instead of grinding it, which would be often a difficult and expensive operation, it is better to burn the limestone and slake it before mixing it with the clay.

The above proportions formed the *best* artificial cements; but he has also recorded as follows:—"After due investigation, we found that any given weight of well burned chalk lime, and consequently of any other pure quick lime, fresh from the kilns, combined with *twice* its own weight *of blue clay, fresh from the river, will form an excellent* water cement;* observing, however, that the quick-lime, after being weighed, must be slaked with excess of water into a thinnish paste, and allowed to remain in that state about twenty-four hours before it is mixed with the clay.

76. *Portland Cement.*—The best known of all English artificial cements, Portland cement, is formed from the ingredients used by Sir C. Pasley, but with different proportions; eight or nine parts of chalk (containing about $7\frac{1}{2}$ per cent. of clay) being mixed with two parts of mud (containing about 70 per cent. of alumina to 30 per cent. of silica). It takes its name from its likeness in color to Portland stone, but is in no way connected with it. The ingredients are chalk and the mud of the river Medway, in the neighbourhood of which it is chiefly manufactured. The ingredients are passed through a crushing mill and carried off by water into large shallow vats ($60' \times 40' \times 8'$). The sediment that is deposited is dried in an oven, and burned in a kiln with alternate layers of coke, at a very high temperature; until it is in a state of incipient vitrifaction. This excessive burning is the distinctive feature of its manufacture. It is now crushed between two iron wheels, ground, and carefully packed in three-bushel casks. The ground cement should be spread out, and allowed to cool for some days on a dry floor before it is packed, as this "air slaking" (perhaps by killing any particles of pure lime which remain in an active state) *is most beneficial to it. When this is not done the* danger of the use of this cement is, that it is apt to swell in the joints of masonry after being applied; but it is admirably adapted for buildings exposed to the action of water, and for external plastering, as it sets very fast and attains great hardness, and does not allow of the formation of

* These proportions by weight are nearly equivalent to a mixture of 1 measure chalk powder to $2\frac{1}{4}$ measures of blue clay. Since 563 grains of quick lime are the produce of 1000 grains dry chalk, which in a state of powder, will fill 1 measure, of which 1114 grains of clay will fill $2\frac{1}{4}$ measures.

vegetation, as the natural cements do. Portland cement does not set so quickly as Roman cement, and if used under water must be at first protected from currents, natural or artificial: but it sets harder under *still* water than it does in air, and stands the action of any current after having been allowed two days to set. If kept dry in casks it rather improves by age, whereas Roman cement loses strength considerably. It has three times the strength of Roman cement, and will safely bear an admixture of 3 to 4 equal volumes of clean sharp sand. Salt water is as good for mixing with it as fresh. Portland cement of the very first quality could be delivered at Delhi from London at Rs. 23 per 400 lbs. cask, or at Rs. 5-2-0 per cubic foot of cement.

77. Various other cements have been invented, among which the Medina cement, made from the Hampshire septaria, and Atkinson's cement, made from the lias limestone, are well known in England.

78. *Scott's Cement.*—Within the last few years, a very remarkable cement has been invented by Colonel H. D. Y. Scott, Royal Engineers. The process is as follows;* The limestone is first burned to quick-lime in the ordinary way; it is then placed in a layer of about $1\frac{1}{2}$ to 2 feet over the perforated arches of an oven, and brought to a dull glow. The fire is then raked out, every orifice closed, and two pots containing coarse unpurified sulphur are pushed in on the fire bars, and ignited so as to distribute pretty equally the fumes of the sulphur; the allowance being fifteen pounds of sulphur to one cubic yard of lime. When it is all consumed, the oven may be opened, and the cement taken out when cool. The fire is applied for about four hours, and the whole process takes one day. It is then ground and sifted through a sieve of thirty meshes to an inch, and spread out on a floor for a day before packing. If the cement be prepared from a pure or feebly hydraulic lime, puzzuolana must be mixed with it, to enable it, to resist the immediate action of water; one part, or rather more, of puzzuolana being added to two parts of cement. When used for plaster, it is mixed with an equal measure of ground chalk.

79. Captain Smith, in his edition of "Vicat on Mortars and Cements," observes that the expense and difficulty attending the grinding of hydraulic cement, which is such an essential element of its success, must very much preclude it from use in situations where this mechanical agency is not readily to be met with; and that, consequently, its use is

* See R.E. Professional Papers, New Series, Vol. X.

better adapted for the vicinities of great towns, where the builder may obtain it ready ground from the manufacturer, or, at least, where he is not destitute of machinery and dependent on unskilled labor. Admitting the truth of this argument, instances may frequently happen where it is worth almost any money to procure a fast setting cement. As in a case which very often occurs in the great irrigation works of India, where some repairs have to be made in a canal fall, or in a revetment exposed to the full force of the stream, and where it is most prejudicial to the irrigation to close the canal for more than a week or two.

80. Colonel H. A. Brownlow, R.E., when in charge of the Eastern Jumna Canal, in a case of this sort, made a most excellent cement from the stone lime and brown alluvial clay procured near the head of his canal, following the directions given in para. 75, and it very well repaid the trouble and expense laid out on it.

81. Hydraulic cement has also been made with considerable success in Madras and at Singapore. Lieut. Morgan, on the Eastern Coast Canal, six miles north of Madras, made a cement of 7 measures of shell lime to 5 measures of clay, following closely Pasley's rules for mixing and burning it. If applied under water, this cement hardened in 24 hours; if applied dry and water let on it in half an hour, it hardened in 8 or 10 hours. The same cement mixed with an equal quantity of soorkee hardened in 48 hours under water, or in 12 to 24 hours if allowed half an hour before the water was let on it.

The cost of this cement was not more than 4 annas per "parah" of 4,000 cubic inches.

Captain Man, at Singapore, found he could make a similar hydraulic cement, of excellent quality, using 5 measures of *slaked lime to 2 of fresh* blue clay.*

82. The following rules for the manufacture of Hydraulic Cements in India are those recommended *by Colonel H. A. Brownlow, R.E., Chief* Engineer for Irrigation in the N. W. P.

The pure rich lime of the lower Himalayan ranges would be the best substitute for chalk. Practically, it is chalk with the carbonic acid driven off, and by its use we should save much wear and tear in grinding and mixing it with the clay. The harder lime-stones would require stone-crushers and extremely hard mill-stones to pulverise them.

* Reports of the Juries of the Madras Exhibition of 1857, page 177.

The clay should, if possible, contain oxides of iron, in any proportion up to 15 per cent.; but if this cannot be secured, any *compact greasy clay free from sand* will answer our purpose, although, perhaps, not quite so well as the other. The proportion of pure lime added can always be modified according to the chemical composition of the clay used.

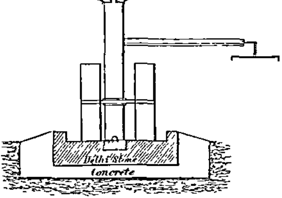
The lime and the clay which it is proposed to mix must be first *thoroughly dried* in the sun, but the clay should be used as fresh as possible, and any exposure of it to sun and air, further than that absolutely necessary to dry it, should be carefully avoided.

The material must then be separately pounded, either by hand or any simple machine, into pieces not larger than a pea, and the pounded materials should be screened so as to ensure the exclusion of coarse lumps.

The pounded materials should then be passed in certain definite proportions through a hopper between a pair of ordinary flour mill-stones adjusted so as to grind them as fine as flour. It will save much wear and tear and do the work more thoroughly, if the materials are passed through *two* pair of stones in succession, the first pair adjusted to grind more coarsely than the second.

The exact proportions of lime and clay to be employed will depend upon the chemical constituents of the materials used, and must be fixed on the spot. Generally speaking, there should not be less than 40, or more than 60, per cent by weight of pure lime, and from 60 to 40 per cent. of clay. Having been fixed, the proportions must be most carefully adhered to, as any carelessness in this matter will of course vitiate all future operations.

The pulverised material should then be mixed in a cylindrical vat with a graduated scale on its side, in the proportion of thirty volumes of powder to ten of *boiling* water, in which has been mixed $\frac{1}{4}$th volume of calcined soda and $\frac{1}{4}$ lb. *of freshly-*burnt and slaked lime.



From the vat, remove the mixture to a basin in which a couple of mill-stones should be made to revolve on their edges round a vertical shaft as in the case of a steam mortar mill. The basin should be only just large enough for the stones to revolve in, should be carefully and smoothly paved with hard stone, and should be surrounded by a rim of wood or masonry 8 inches to 12 inches high. The stones should be fixed at slightly unequal distances from the vertical shaft, so as not to run exactly in each other's tracks, and at the outset I should think it would amply suffice to move them by animal power as shown in sketch. They could afterwards be easily, connected with the water wheel that drives the mills.

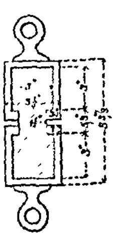
From the edge runners, the mixture should be taken to a pug-mill, and, when thoroughly pugged, (being passed through the pug-mill 2 or 3 times if necessary,) should be cut off in small bricks or lumps, not exceeding 2 inches or 2½ inches in thickness, as it comes out of a shoot fixed at bottom of mill.

It may not be amiss to remark here that too much pains cannot be bestowed on the thorough incorporation of the raw materials, and in keeping them clean and free from sand and foreign ingredients during the process. As far as any chemical action is concerned, the clay remains almost inert after the mixture has attained a dull red heat, so that it is most important to bring it into the closest contact with the lime before the burning commences. The presence of sand tends to produce vitrifaction during burning, and is most prejudicial to the cement; clay containing more than $\frac{1}{20}$ of sand should be rejected.

M. Lipowitz objects to drying in the air, and quotes two examples where doing so was found to be most injurious to the cement. But the English manufacturers expose their raw cement freely to the air in the reservoirs, where it sometimes lies for a couple of months before it is burned; and in one factory, I saw it being wheeled direct from the drying reservoirs to the kilns. So that, until experience shows us in India that kiln-dried, is stronger than sun-dried, cement, I should recommend stacking the blocks of raw cement, as removed from the pug-mill, in drying hacks like bricks.

When *thoroughly* dry, the blocks of raw cement should be burned, either in clamps with dried cow-dung, or in a good lime kiln with thoroughly dry wood, or with charcoal, as experience on the spot may show to be most advantageous. The proper degree of exposure to heat should be ascertained and carefully adhered to. The higher the heat to which it is exposed the greater the density of the cement, the greater also its strength and its ultimate degree of induration; while the lighter cements have the property of setting more rapidly.

The burnt cement should then be pounded until it can pass through a screen with meshes the size of a pea, and finally be ground as fine flour so that it can pass through a No. 60 gauge sieve (3600 meshes to a square inch). It should then be allowed to cool thoroughly on a dry floor before packing.



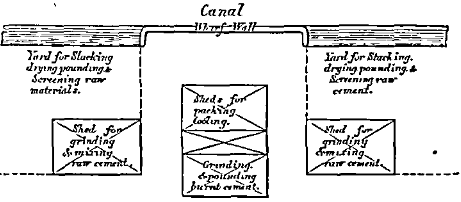
Thickness of brick = 1½ inches

The cheapest packing for India would be in bags or sacks. These would not have any sea voyage to undergo, and the cement would, in all probability, be used tolerably fresh. Where it had to be sent long distances, small barrels could doubtless be purchased at advantageous rates from the nearest commissariat depôt

A number of samples should be made up of cements formed according to these directions. The samples, when burnt, should be finely pulverised, and, when cool, should be moulded into bricks of the form shown by the shaded portion of marginal diagram. There should be at least a dozen bricks of each sample, and they should be allowed to set under still water for seven days after they have been taken out of the moulds. The lower of the two iron clips shown in the diagram should then be loaded until the bricks are torn in two, and if any of the samples prove themselves capable of supporting an average

weight of 225 to 250 lbs. on the area 1½ inch square (or 2¼ square inches), I think we may safely adventure upon the manufacture. I have been particular in giving dimensions of the sample brick, as I wish to adhere as exactly as possible to the form of test generally used in England. It would be instructive and interesting to make up and treat in the same way bricks of the best "kunkur" lime.

The samples mentioned above should be carefully made up in the manner laid down, accurately labelled, and tested. The strongest composition having been thus ascertained, steady and persevering efforts at economical production must be made. I am most strongly convinced of the good policy of beginning in the simplest manner, consistent with economy and efficiency. Mistakes can then be easily and inexpensively rectified. The site of the factory should, from the very first, be laid out with an eye to expansion of business, and economical working on a large scale. There should be no carrying backwards and forwards, the general arrangement of the works being somewhat as indicated below.



In conclusion, I must add a few words on the manipulation of the manufactured cement, which, are, I think, necessary, as it has not been hitherto extensively used in India, and the best cement may be utterly ruined by careless handling on the works. *In the first place, only just so much of it as is required for immediate use should be made up at any one time, as when once it has commenced to harden it cannot be worked up again* like a mortar containing rich lime. In mixing it with sand or

gravel, *the ingredients should be well mixed together in a dry state*, before any water is added. In adding the water, only pour in enough to make a stiff paste, as flooding the cement is most prejudicial to it. The sand used should be clean and sharp, and when cement is used in brick-work *the bricks must be thoroughly saturated in water before use*, otherwise they will absorb the moisture necessary for the proper setting of the cement. When used under water, cement must until it has set, be protected from any current.

83. Hydraulic Limes.—Hydraulic *Limes* are of much use for all the *ordinary conditions of building*, as on the one hand where the building is not likely to be exposed immediately to the action of water, and where its action is not severe; or where on the other hand it would be improper to use pure limes, as explained before. In the use of hydraulic limes, moreover, there is far less danger than in the case of cements, of an unskilled or careless bricklayer spoiling the work.

Natural hydraulic limes vary much in character, containing from 8 to 30 per cent. of clay. Indeed the larger proportion of limes comes into this class, especially of the hard blue limestones; but their color or hardness, must not be taken as a certain test. Their properties have been known since the time of the Romans; but Smeaton while experimenting for the Eddystone Light-house, was the first to detect that the reason of their being able to set under water lay in their containing a portion of clay. To this class belong most of the kunkurs of this country, and the blue Lias lime, so well known in England.

84. Where natural hydraulic limestones are not found, their place may be supplied artificially in the same way as in the case of hydraulic cements; and, as Vicat remarks, these artificial limes have this advantage, that by being able to regulate the proportions of the ingredients, we can give them whatever degree of energy we please, and cause them at pleasure to equal or surpass the natural hydraulic limes. All writers, however, agree that it is better to use a natural, than an artificial, hydraulic lime, when the former can be readily procured,

Vicat has divided his artificial hydraulic limes, into two classes; 1st, Those made out of slaked limes and a certain proportion of clay, the mixture being then calcined; 2ndly, Those made from any very soft calcareous substance, such as chalk or tufa, reduced to a paste in water and then mixed with clay and burned. The second method is much the cheaper, but according to Vicat, not so good as the first, "in consequence of the rather less perfect amalgamation of the mixture. In fact it is impossible by mere

mechanical agency to reduce calcareous substances to the same degree of fineness as slaked lime." It appears that General Pasley did not find this disadvantage in his chalk experiments.

85. The following is the way in which the first of these two processes has been carried out in France. The lime being slaked to powder was divided into portions of 8·8 cubic feet ($\frac{1}{4}$ cubic metre) each, and with each of these was mixed 1·059 cubic feet (0 m. 03 cent.) of gray clay which had been dried, reduced to fragments, and beaten into fine pulp with water. The lime and clay were together beaten with pestles into a paste. The portions were then accumulated into large heaps, which were allowed to acquire so great a consistency as to admit of their being cut into fragments by a shovel. These fragments were spread out to dry and then burnt in the kiln.

86. At Meudon, near Paris, hydraulic lime is made according to the second method above given, as follows:—

The materials used are the chalk of the country and clay (containing alumina 63, silica 28, oxide of iron 7). The clay is broken into lumps, the size of one's fist. Four measures of chalk and one of clay are thoroughly mixed together in a circular basin of $6\frac{1}{2}$ feet radius, under a mill-stone set up edgeways, and a strong wheel attached to a set of harrows and rakes, which revolve in it by a two-horse gin; the basin being kept supplied by water. After an hour and a half working, nearly 35 cubic feet of a thin pulp is obtained, and drawn off by a conduit and passed through a series of reservoirs, where the solid material sinks to the bottom, leaving the water to be carried off into the next reservoir, and ultimately drained into a cesspool. The sediment left is now moulded into solid prisms (about 73 cubic inches) and these prisms are thoroughly dried and then burnt in the kiln in the usual way.

It will be observed that this process is very similar to the one employed for making Portland cement (para. 76), and that the ingredients used are the same; the essential point of difference being that in the Meudon hydraulic lime manufactory, calcination stops when all the carbonic acid gas has been driven off; whereas in the case of Portland cement it is pushed to a point which produces vitrification in a considerable portion of the kiln.

87. At Kurrachee, artificial hydraulic lime has been very successfully made by Mr. Price, the Superintendent of the Harbour Works.

Ordinary rich (fat) lime slaked to powder, is mixed with clay, in the proportions of $5\frac{1}{2}$ parts, by measure, of lime, to 1 part of clay.

The rich lime used has been generally made from the hard crystalline limestone procured from the "Gizree" hills, near Kurrachee.*

The clay is procured *in situ* from the bed of the Lyaree river, and is of the description that might be used for bricks or coarse pottery.

The mixture of the lime and clay is made in a mortar pan worked by steam power,† a sufficient quantity of water being added to bring it to the consistency of moderately stiff mortar. The amalgamation should be very thoroughly effected, as upon this greatly depends the quality of the lime.‡

The mixture is then made by hand into balls of about the size of a large orange which are laid out on the ground in the sun to dry. When thoroughly dried, which takes from two to six days according to the weather, the balls are burned in a kiln; or if the lime is not likely to be soon required, they are stored in a shed. It is most important that the balls should be thoroughly dried before burning.

Some further details regarding this Kurrachee lime will be found in paras. 105 and 106.

88. HYDRAULIC MORTARS. Along with hydraulic limes may be classed those hydraulic mortars which are formed from a mixture of common or feeble hydraulic lime with a natural or artificial puzzuolana.§ The two principal *natural* ingredients in Hydraulic mortars are puzzuolana and trass. The former, a volcanic dust from the neighbourhood of Mount Vesuvius, in Italy, was used as early as the time of the Romans, as we find from Vitruvius; it was not used in England until Smeaton employed it in building the Eddystone Light-house. Trass is a similar volcanic product, found near Andernach, on the Rhine.

89. Aden pumice is used in Bombay as a puzzuolana, and gives excellent results, it is mixed with equal parts of Salsette lime and sand, to form mortar. Its analysis by Dr. Lyon shows, its constitution to be as follows.—

* Shell lime would probably be found a tolerable substitute where limestone is not easily available.

† At the Gorree regulating bridge, the mixture was made by a stone roller, running in a circular trough of brickwork and worked by bullocks.

‡ If the mixture is properly made, the balls after drying should show a uniform gray colour when broken, the white specks of lime not being easily distinguishable.

§ Vicat's nomenclature has been adopted in calling all these ingredients of mortar containing burnt clay, "artificial puzzuolanas."

Water,	1·81	Water,	1·81
Gypsum,	46·05	Sulphate, of Lime,	36·41
		Water of Combination,	9·64
Silicates, &c.,	52·11	Silica,	31·00
		Alumnia,	5·17
		Sesquioxide of Iron,	3·05
		Magnesia,	0·57
		Alkaline bases, Water and loss,	12·32
	100·00		100·00

The chief ingredients of trass and puzzuolana are burnt silica and alumina; and, in imitation of them, many artificial compounds of clay have been formed, and are largely used. These are frequently termed "artificial puzzuolanas." The pounded brick, or "soorkee," of this country, is one of this class.

General Treussart has recorded very fully a series of experiments made by him on the formation of artificial puzzuolanas from the calcination of clay. The conclusions he arrives at were:—1st, That the presence of lime in the clay burnt has a great influence on the manufacture of puzzuolana. While clays containing from 10 to 20 per cent of lime required to be heated very little, and deteriorated in quality, by being thoroughly calcined, those containing little or no lime require to be fully calcined to bring out their excellent qualities; 2nd, That clays containing a large proportion of sand are not so suitable for making puzzuolanas as those which, having more alumina in their composition, are greasy to the touch, 3rd, That the artificial puzzuolana once made, requires no further care, "for neither the influence of the air nor humidity will deprive it of any of its properties." This last is a very important fact, for we may conclude from it that puzzuolanas formed by pounding bricks may be made irrespective of the antecedents of the bricks, although the original composition of the brick earth affects the question of whether over burned or under burned bricks should be pounded for "soorkee."

90. One important fact must be noticed with regard to the use of puzzuolanas; viz., that dependence cannot be placed on them, or at least on the artificial ones, for works which will be exposed to the action of salt water. Smeaton used natural puzzuolana in the construction of the Eddystone Light-house and found it to stand admirably; but in various French sea-coast works at Brest, Cherbourg, Algiers, and elsewhere, where artifi-

cial puzzuolana was used, the mortars after appearing to set very satisfactorily, and the favorable appearance lasting even for three or four years, have disintegrated and fallen to powder. Vicat attributes this to the action of the hydrochloride of magnesia upon the particles of mortar which were not entirely carbonized. These particles, taking up the magnesia, and passing into hydrocarbonate of lime and magnesia, would crystallize in a different way from the ordinary carbonate of lime, and this would doubtless lead to the disintegration of the whole mass.

Whether or not this is the right solution of the question, there is no doubt about the fact; and the practical deduction to be drawn from it is, never to employ *artificial* puzzuolanas for any works of importance where water charged with salts is likely to affect them.

91. Where clay is to be burned expressly for puzzuolana, it should be done by making it into balls about the size of an apple, drying them, and burning them in an ordinary lime kiln; or the clay may be pulverized and strewed in a thin layer over a plate of iron heated to a point between cherry red and forging heat.

It is only by experiment that it can be determined what bricks make the best soorkee or puzzuolana; for, as has been shown, an underburnt or "peela" brick furnishes the best if it contain a certain proportion of lime, while the brick should be thoroughly burnt or "pucka" if it contains no lime. To determine the presence of lime, take a little of the brick-dust, put it in a glass, and pour over it a little diluted hydrochloric acid, or even strong vinegar; effervescence ensuing will show that lime is present; and the quality may be determined as explained in para. 71. Another test of the best soorkee is by making three small balls of mortar; using in each case the same proportions of lime and soorkee; but the latter ingredient being made from bricks underburnt, burnt, and overburnt, respectively, from the kiln from which it is proposed to obtain the supply. The three balls may then be put into vessels of water, and in a few days examined, and that soorkee which has produced the hardest mortar preferred.. In a country like this, however, where bricks are often made so carelessly, and out of such very indifferent clay, special care should be taken to procure bricks for making puzzuolana which really are clay, and do not contain a large proportion of sand.

Having then obtained good properly burnt brick-earth, in the form of bricks or otherwise, nothing remains but to grind it down into impalpable

powder; this is absolutely indispensable to effect the intimate union which is necessary between the lime and puzzuolana to enable them to set under water, and too much labor can hardly be spent on it.

92. Regarding the combinations of lime and clay, M. Courtois states "If crude clay be mixed with various proportions of lime, pastes are formed which have more consistence than clay alone; this paste put under water acquires at the end of three days a certain hardness which it preserves afterwards indefinitely; it attains its maximum of consistence when 1 part of lime is mixed with 9 parts of clay; this paste after three days resists the pressure of the thumb. When a mixture of lime and clay exposed for some days to the air, has lost a part of its water, without having been dried too rapidly, it may be afterwards immersed without sustaining any alteration, provided the volume of lime be not greater than one-third that of the clay; the proportion of lime might be less but should not be greater. A mortar of this sort might be used in the construction of cisterns, reservoirs, and other works, where an insoluble rather than a strong mortar is needed. The quality of augmenting the resistance of lime which crude clay possesses, appears to have been known for a long time in Champagne, where all the wooden houses are covered exteriorly with a plaster composed of lime and a white argillaceous and calcareous earth. The floors are also made with a plaster of the same nature, and when not dried too rapidly they resist perfectly. This species of *puddling* would be well worthy of trial in some districts where the material is plentiful.

93. Strength of Mortars.—*Mortars* may be tested with a view to discover their hardness, their resistance to crushing, their adhesiveness to bricks, their internal tenacity or cohesion, the time they require to harden, and the amount of sand which may be safely and economically used in their composition.

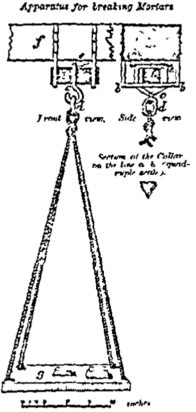
The force with which mortars in general adhere to other materials, depends on the nature of the material, its texture, and the state of the surface to which the mortar is applied. Mortar adheres most strongly to bricks: and more feebly to wood than to any other material. Among stones its adhesion to limestone is generally greatest; and to basalts and sandstones least. Among stones of the same class, it adheres generally better to the porous and coarse-grained, than to the compact and fine grained. Among surfaces it adheres more strongly to the rough than to

the smooth. The adhesion of common mortars to brick and stone for the first few years, is greater than the cohesion of its own particles. With hydraulic cements the reverse is the case; they appear also to adhere to polished surfaces as well as to rough ones. Rondelet estimated 15 to 30 lbs. per square inch, as the force acting perpendicular to the plane of the joint required to tear asunder stones connected with common mortar after six months union, and only 5 lbs. per square inch as the *detrusive* force required to separate the same surfaces acting parallel to the joint.

Pasley considered that the adhesive force of hydraulic cement to stone might be taken as high as 125 lbs. per square inch, when the joint was thoroughly hardened. But as the exterior part may often harden long before the interior, he thought in questions of doubt on the subject from 30 to 40 lbs. per square inch, was as much as should be calculated on.

94. To ascertain the strength of mortars, Treussart used the following process:—Two pendant iron stirrups, *bb*, were attached to a horizontal beam, *f*, parallel to each other, and distant 4 inches in the clear, the lower parts being exactly level. On these stirrups a prism of mortar, *a*, was placed, passing it through a loosely fitting rectangular collar of iron, *c*, terminated below by a hook. To this hook was suspended a common scale pan, *g*, by means of ropes and an iron link, *d*. The upper horizontal bar of the collar which pressed on the mortar had its transverse section of the form of a rounded wedge; and being brought against a check, *e*, it pressed exactly on the middle of the prism. The scale pan was then loaded with successive weights, until the prism broke.

Apparatus for breaking Mortars



The prisms of mortar were made by mixing the ingredients well together, adding the water till the consistency was like honey, and passing the mortar seven or eight times under the trowel.

The mortar was then put into wooden boxes exactly $6 \times 3 \times 3$ inches, and left in the air 12 hours. They were then placed in a large tub of water in a cellar, and there left till the thumb could make no impression on them. Noting from time to time the degrees of hardness of each kind. At the end of a year they were withdrawn, and scraped down on their four faces till they measured 6×2 inches square. This was done to prevent any error arising from the surface of the mortar being harder than the interior. When the mortar experimented on was not hydraulic it was not immersed in water, but merely left to harden in a cellar.

The trial of mortar, by crushing prisms under a weight, is not a very sure one; as it is difficult to judge the moment when they begin to yield, the angles occasionally breaking off before the middle; and it is not clearly seen when the substance under trial has really yielded to the load. A preferable mode is that explained in para. 82.

95. Sir Charles Pasley made some experiments in the same way as Treussart had done, but put more stress on the relative adhesiveness of various mortars to bricks and different sorts of stones, than on their resistance to transverse strain. To determine this adhesiveness, he first built a series of horizontal brick beams out from the face of a wall, each day adding one brick till the beams broke. The brick to be added was immersed for about half a minute in water, the face of the last brick being wetted at the same time; a thin coat of mortar was then applied to the last brick, and a thicker one to the new brick. The two were then joined, and a man held the last brick pressed against the other for from five to ten minutes till it adhered of itself. It this way with his cement of 4 parts chalk, to 5 of clay, he made a beam of 31 bricks, or 6 feet $11\frac{1}{2}$ inches long, weighing 189 lbs., which broke sixteen hours after the last brick had been placed.

Not altogether satisfied with this experiment, Pasley tried another system. He cut mortises about $\frac{3}{4}$-inch deep in the sides of a number of bricks, and fitted into them pairs of iron nippers. The bricks were then cemented together in pairs by their flat surfaces ($9 \times 4\frac{1}{2}$ inches). The upper nipper was connected by an iron rod to the top of a gin, and the lower to a scale board, on which were piled weights until the joint broke. This affords an excellent test of the adhesion of the mortar to the brick, and of its own cohesion to itself.

Colonel Totten, United States Engineers, tested the *tenacity* of some mortars in a similar way, by joining bricks crossed at right angles, the surface of contact being 16 square inches. By *this means* he was able to fix round the projecting ends iron stirrups to which the weights were hung, without requiring to cut holes in the sides of the bricks.

96. The *following* table. (*Table I*) shows Colonel Rancourt de Charleville's estimate of the resistance to rupture of limes of different quality, and of various stones.

TABLE I

Description of lime or stone experimented on	Comparative resistance.
Eminently hydraulic mortars of quartzose sand, . . .	11 to 6
Hydraulic mortars, . .	6 „ 4
Feebly hydraulic mortars, ...	4 „ 2
Bad ordinary mortar of common lime and quartzose sand, such as mason's use, ...	Scarcely above 1
Soft gypsum and freestone, . .	1 to 6
Lavas and tufas, ...	6 „ 10
Soft limestone, ...	10 „ 20
Brick of good quality, ...	12
Hard limestone, . .	20 to 40
Granite, ...	40 „ 50
Basalt, ...	50 „ 70
Quartz rock, ...	70 „ 80

97. Tables II. and III., go to prove the fallacy of a theory believed among builders from the time of Vitruvius downwards, and probably fairly confuted for the first time by Colonel Scott, R.E., viz., that a certain amount of sand positively increases the strength and adhesion of mortars. Its beneficial action being assumed, various fanciful theories have been put forward in explanation of it; the most generally received being that the particles of the lime shrink in setting, and unless sand be mixed with it, cavities are left all through the mortar. Scarcely any two authors, however, have agreed in determining how much sand should be used to form the

TABLE II.*

SHOWING the strength of prisms of mortar broken transversely.

Name of cement, &c., experimented on.	Number of trials.	Age when fractured.	Composition of Mortar. The lime being measured in unslaked powder. Nett cement.	1 sand, 1 cement or lime	2 sand, 1 cement or lime.	3 sand, 1 cement or lime.	4 sand, 1 cement or lime.	Remarks.
Roman cement, ...	5	11 days, ..	400	270	178	154	140	Capt. Schaw, R.E.
"	5	13 months,	..	562	214	102	..	Capt. Schaw, R.E.
Portland cement, ...	5	30 days, ..	..	529	538	323	158	Capt. Schaw, R.E.
Scott's "	5	"	..	382	333	263	242	Made from feeble hydraulic chalk lime. Capt. Schaw, R.E.
" "	5	13 months,	..	780	650	410	..	Made from feeble hydraulic chalk lime. Capt. Schaw, R.E.
Lias lime, ...	5	"	..	158	..	..	..	Capt. Schaw, R.E.
Roorkee cement, ...	4	26 days, ..	598 5	..	..	..	..	Lieut. Moncrieff, R.E.
Chalk lime, ...	2	396 days, ..	..	..	..	104		Pasley, 3½ sand used.
Obernai lime, ...	..	12 months,	323	..	260	154	..	Mean of Treussart's results.
Bath stone, ...	5	..	666	..	..	..	..	Pasley.
Well burned bricks, . . .	5	..	725	..	..	..	..	Pasley.
Common Strasburg bricks, . .	..	..	462	..	..	..	..	Treussart.

* See page 83, Vol. XI, R.E. Professional Papers.

TABLE III.

SHOWING the effect of sand on mortars as determined by various experiments. The resistances are given in lbs., per square inch; the trials having been made by tearing joints asunder.

Nature of lime or cement.	No. of trials.	Age of mortar in days.	Composition of Mortar. Lime estimated in powder previous to slaking. For one part of lime or cement powder. 0 sand.	1 sand.	2 sand.	2½ sand	3 sand	4 sand.	5 sand	6 sand.	Remarks.
Roman cement,	5 to 15	11	40·0	27·9	17·8	..	15 4	14 9	7 3	..	Experiments at Chatham, 1867. * Bricks broke, the cement joint adhering.
Medina do.,	5 „ 15	11	40·0	35·2	27·1	..	20 1	14 9	8 3	7·5	
Atkinson's do.,	5 „ 15	11	..	38 5	17 5	..	7 9	4 9	..	..	
White's Portland do.,	5 „ 15	11	*	50·4	43 3	..	30 3	42 0	23·8	26·5	
Scott's cement,	5 „ 15	11	29 2	28 6	30·8	..	32 8	28 1	19 4	18 4	
Ditto,	5	30	52 1	51·4	52 7	..	52 8	33 1	39 8	31 7	
White's Portland do.,	5	30	*	..	66 7	..	50 5	52 1	35 6	36·5	
Roman do.,	5	30	49·0	42·4	23 6	..	..	..	..	..	
Medina do.,	5	30	51 2	53 8	37 0	..	..	..	..	..	
Lias lime,	2	61	..	..	..	8 85	9 38	..	..	..	Experiments at Holyhead. Exposed to the air.
Ditto,	2	122	..	..	..	5 6	9 38	..	..	..	
Ditto,	2	365	..	..	..	13 6	11·53	..	..	..	
Ditto,	2	61	..	..	..	5·63	7·57	..	..	..	Experiments at Holyhead. Immersed in water.
Ditto,	2	122	..	..	..	6·56	5 28	..	..	..	
Ditto,	2	365	..	..	..	1 61	..	..	..	..	
General Totten's Americal mortars, made of fat lime,	..	180	..	23·4	21·1	20·1	16·2	..	..	..	Lime measured in slaked paste.
	..	4½yrs.	..	40·4	31·9	29 8	22 6	..	..	..	
Pasley's cement,	3	11 to 17	27·3	5 6	..	..	..	..	..	..	Pasley's Table IV. Amount of sand not given.
Chalk lime mortar,	6	30 yrs.	3·9		..	..	..	..	..	..	

best mortar, or as to the extent to which the proportion of sand should be varied according as the mortar is hydraulic or not. The lime in mortar does no doubt shrink if dried rapidly; so that in plastering the surface of a wall where freedom of shrinkage is of more consequence than hardness or adhesion, and where (especially in a country like India), the mortar dries very rapidly, it is beneficial as well as economical to mix sand with the lime. But, in anything but the very thinnest masonry, cracks from drying too fast are not to be apprehended; and Tables II. and III., show indisputably how much mortars made both from cements and limes lose in strength as sand is added.

The prisms in Table II., were 3 inches between the points of support and 2 inches square in section; except the Roorkee cements, which were 4 inches in bearing, 2 and 2½ inches square in section. None of them had been immersed in water. They were loaded at their centres. The Roorkee cements were made precisely according to Pasley's directions, with one part of fat lime made of Ganges boulders, and 2 parts of hard blue Hurdwar clay.

The prisms of mortar in Table II.* set in water, or were left in a damp cellar for a year, while Colonel Totten's were subjected to a pressure of 600 lbs. at the time of formation, which probably squeezed all the superfluous moisture out of them.

The prisms of both were 2 inches square in section; Treussart's 3 inches, and Totten's 4 inches, between the points of support. The Smithfield lime used by Totten, and the Strasburg limes, are both pure fat limes.

98. The next Table is from Vicat's† work, and shows the necessity of keeping hydraulic mortars moist until setting has taken place. It will be observed that the injury is greater in proportion as the lime used is more hydraulic; so much so that Vicat estimates, that an eminently hydraulic lime may lose by too rapid drying, as much as ⅔ths of the strength it would acquire if allowed to dry slowly. He therefore recommends that all masonry built in hot weather should be kept watered till the mortar has set, and Raucourt de Charleville suggests the use of wet straw mats to be laid over the work. The importance of attending to this point in India need hardly be alluded to.

* Extracted from Treussart's Tables, II., III , and XXXVI. ; and Col. Totten on Mortars.
† Vicat, Table XIII , Chapter XI.

TABLE III.

SHOWING the effect of sand on mortars as determined by various experiments. The resistances are given in lbs., per square inch; the trials having been made by tearing joints asunder.

Nature of lime or cement.	No. of trials.	Age of mortar in days.	COMPOSITION OF MORTAR LIME ESTIMATED IN POWDER PREVIOUS TO SLAKING. For one part of lime or cement powder. 0 sand.	1 sand.	2 sand.	2½ sand.	3 sand.	4 sand.	5 sand.	6 sand.	Remarks.
Roman cement,	5 to 15	11	40·0	27·9	17·8	..	15·4	14·9	7·3	..	Experiments at Chatham, 1867. * Bricks broke, the cement joint adhering.
Medina do.,	5 " 15	11	40·0	35·2	27·1	..	20·1	14·9	8·3	7·5	
Atkinson's do.,	5 " 15	11	..	38·5	17·5	..	7·9	4·9	..	..	
White's Portland do.,	5 " 15	11	*	50·4	43·3	..	30·3	42·0	23·8	26·5	
Scott's cement,	5 " 15	11	29·2	28·6	30·8	..	32·8	28·1	19·4	18·4	
Ditto,	5	30	52·1	51·4	52·7	..	52·8	33·1	39·8	31·7	
White's Portland do.,	5	30	*	..	66·7	..	50·5	52·1	35·6	36·5	
Roman do.,	5	30	49·9	42·4	23·6	..	..	..	..	..	
Medina do.,	5	30	51·2	53·8	37·0	..	..	..	..	..	
Lias lime,	2	61	..	..	..	8·85	9·38	..	..	..	Experiments at Holyhead. Exposed to the air.
Ditto,	2	122	..	..	..	5·6	9·38	..	..	..	
Ditto,	2	365	..	..	..	13·6	11·53	..	..	..	
Ditto,	2	61	..	..	..	5·63	7·57	..	..	..	Immersed in water.
Ditto,	2	122	..	..	..	6·56	5·28	..	..	..	
Ditto,	2	365	..	..	..	1·61	..	..	..	..	
General Totten's Americal mortars, made of fat lime,	..	180	..	23·4	21·1	20·1	16·2	..	..	..	Lime measured in slaked paste.
	..	4½ yrs.	..	40·4	31·9	29·8	22·6	..	..	..	
Pasley's cement,	3	11 to 17	27·3	5·6	..	..	..	..	..	..	Pasley's Table IV.
Chalk lime mortar,	6	30 yrs.		3·9	..	..	..	..	..	..	Amount of sand not given.

best mortar, or as to the extent to which the proportion of sand should be varied according as the mortar is hydraulic or not. The lime in mortar does no doubt shrink if dried rapidly; so that in plastering the surface of a wall where freedom of shrinkage is of more consequence than hardness or adhesion, and where (especially in a country like India), the mortar dries very rapidly, it is beneficial as well as economical to mix sand with the lime. But, in anything but the very thinnest masonry, cracks from drying too fast are not to be apprehended; and Tables II. and III., show indisputably how much mortars made both from cements and limes lose in strength as sand is added.

The prisms in Table II., were 3 inches between the points of support and 2 inches square in section; except the Roorkee cements, which were 4 inches in bearing, 2 and 2½ inches square in section. None of them had been immersed in water. They were loaded at their centres. The Roorkee cements were made precisely according to Pasley's directions, with one part of fat lime made of Ganges boulders, and 2 parts of hard blue Hurdwar clay.

The prisms of mortar in Table II.* set in water, or were left in a damp cellar for a year, while Colonel Totten's were subjected to a pressure of 600 lbs. at the time of formation, which probably squeezed all the superfluous moisture out of them.

The prisms of both were 2 inches square in section; Treussart's 3 inches, and Totten's 4 inches, between the points of support. The Smithfield lime used by Totten, and the Strasburg limes, are both pure fat limes.

98. The next Table is from Vicat's† work, and shows the necessity of keeping hydraulic mortars moist until setting has taken place. It will be observed that the injury is greater in proportion as the lime used is more hydraulic; so much so that Vicat estimates, that an eminently hydraulic lime may lose by too rapid drying, as much as ⅘ths of the strength it would acquire if allowed to dry slowly. He therefore recommends that all masonry built in hot weather should be kept watered till the mortar has set, and Raucourt de Charleville suggests the use of wet straw mats to be laid over the work. The importance of attending to this point in India need hardly be alluded to.

* Extracted from Treussart's Tables, II., III., and XXXVI.; and Col. Totten on Mortars.
† Vicat, Table XIII., Chapter XI.

TABLE IV.

MORTARS compared in regard to the influence of desiccation.

Proportions.		Absolute resistance of the mortars when 22 months old, per square inch.		Observations.
Lime slaked by immersion and measured in paste.	Common granite sand.	When exposed after manufacture in a loft of 59° Fahr.	First put under ground, afterwards removed by degrees into the air.	
		lbs		
Hydraulic lime, 190	150	92·23	165·68	Each of these results is the mean of a number of experiments.
Feebly hydraulic lime, 180	150	44·12	73·73	
Common rich lime, 180	150	45·55	51·24	

99. Lime Burning.—Lime kilns may be divided into two classes, 1st, the *intermittent kilns*, or those in which the fuel is all at the bottom, and the limestone built up over it; and 2nd, the *running* or *perpetual kilns* in which the fuel and limestone are built in a similar way to that in which bricks are burned in a clamp or "pajáwah," in alternate layers. In the former, one charge of lime is burned at a time; and when the burning is complete, the kiln is completely cleared out previous to burning a second; while in the latter, fresh strata may be constantly added at the top as the calcined lime is withdrawn from the bottom. In the intermittent kiln, the limestone charge rests upon arches of the same material, rudely constructed of large pieces laid dry. A small fire is lighted below these arches, and quite at the back; this is gradually increased towards the mouth as the draught increases. The opening is then regulated to secure the proper degree of combustion, new fuel is added to keep it to that point, while the air which enters by the fire door, carries the flame to all parts of the arch, and gradually brings the whole to a state of incandescence. Care must be taken *in forming the arches, that the stones of which they are formed are not* such as will crack and burst with the application of heat; as they might cause the arch to give way, and the charge to fall in. The *perpetual kiln* is the more economical of the two in fuel, but at the same time is more difficult to manage. A mere change in the direction or intensity of the

wind, a falling in of the inner parts of the charge, an irregularity in the size of the lumps of limestone used, may all be sufficient to alter the force of the draught, and to cause an excess or deficiency of calcination. A change in the quality of the fuel used will also evidently alter the time of burning; and sometimes a kiln of this description, after working for sometime very well, suddenly becomes out of order without any apparent reason. So that the management of such a kiln must be an affair of experience and caution alone; but notwithstanding the precautions required, the perpetual kiln is one quite as largely used as the other.

100. The fuel used for kilns must of course depend very much on the products of the country or district in which they stand. In Britain, coal and coke are the only two fuels ever used. If any use can be made of the distillation of the coal, there is then an evident advantage in using coke; for the gases which the latter gives off arrive at once at their highest degree of temperature, while this temperature is only arrived at with the former, at the end of its combustion, when in fact the coal is coked in the kiln. The quantity of smoke that escapes from the kiln, while the coal is being burned, may be taken as an indication of the combustible wasted. A kiln in which coke is the fuel, will yield nearly one-third more calcined lime in a given time than one in which coal is used.

In many countries, wood (which is not well adapted for perpetual kilns) is the only fuel. In India, wood, dried palm leaves, charcoal, and dried cow-dung, are the ordinary fuels. The varieties of wood of course vary with the resources of the locality.

101. The shapes given to the interiors of kilns are very different. The object sought is to obtain the greatest uniform heat possible with the smallest expenditure of fuel, for which purpose thick walls are necessary to prevent radiation.

Intermittent Kilns.—In *Plate* XVIII., are various forms of intermittent kilns used in different countries. *Fig.* 1 is what is termed in France a field kiln *(four de campagne)*, and is designed for temporary use, where a large quantity of lime is wanted in a short time. It consists of merely an oven-shaped vault of limestone, upon which a stack of the same material is built up in a cylindrical form. The whole is then surrounded by a wall of beaten earth, and supported outwardly by coarse wattlings. According to Vicat, in this kiln a cubic yard of lime requires from 1·64 to 2·234 cubic yards of oak as fuel.

102. *English kiln.—Fig.* 2 is a cross section of a common form of intermittent kiln, used for burning chalk lime on the river Medway, Kent; the fuel used being coal. These kilns are generally built in pairs, as two charges freight one river barge. *a*, is a large aperture, where the chalk is thrown in (the ground being higher behind); *b*, the door where the lime is taken out; *cc*, the furnaces, the bars going right across the kiln. The inside of the kiln is lined with fire-bricks, set in a mixture of equal parts of brick-earth and sand. The lime takes 60 hours to burn; and 20 hours after they have ceased to put in fuel, the lime should be cool enough to admit of its being taken out. The volume of the charge diminishes as the kiln burns; the out-turn for a pair of kilns beingf rom 110 to 120 cubic yards. The fuel required for this quantity is nine tons of coal, and an allowance of 1 or 2 lbs coarse gunpowder; which is exploded occasionally from a gun barrel inside the kiln, to keep soot from forming and checking the draught.

103. *American Kiln.—Fig.* 3 is a section of an intermittent kiln, used in America, the fuel being wood. A hollow dome from 3 to 6 feet high is formed of the blocks of stone, resting either on the bottom of the kiln or on the fire grates. It is made large enough to hold all the fuel, which, cut into short lengths, is piled round it endwise. The stone is gradually brought to a red heat in 8 or 10 hours, avoiding any sudden increase of temperature, as it is apt to shiver the stones and break down the dome. After this heat has been arrived at, it is kept up uniform until the calcination is complete, indications of which are given by the volume of the charge being diminished to about ⅚ths of its original mass, by the broken appearance of the stone forming the kiln, and by the ease with which an iron bar may be forced down through the charge. This kiln is shown as built on the face of a steep bank.

104. *Dehra Doon Kiln.*—On the next page is a plan and section of a lime kiln in common use by the native lime burners of Dehra Doon.

It consists of a cylindrical pit dug near the steep bank of a river, the bottom roughly paved with flat stones, the sides being boulders set in mud.

Openings, B, are made out to the bank of the river, through which the fuel is ignited, and which afterwards act as draught holes. The kiln is filled with green wood; a heap of billets of dry wood on end, A, being placed in

INTERMITTENT KILNS.

1
ıch

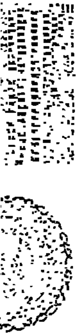


Fig 2
English

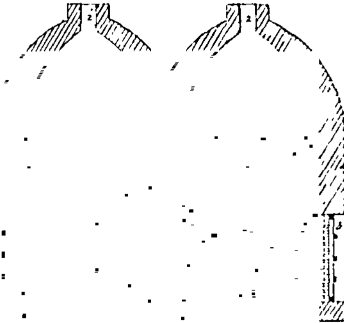


Fig 3
American

The doors of the chambers not in action are closed, the chinks being plastered over with clay.

After the burning, one day is allowed for cooling the kiln, after which the doors may be opened and the lime drawn.

The kiln requires for burning from 400 to 450 maunds (maund equal 82 lbs) of firewood, if jhow, be used; if babool, 360 to 400 maunds.

The return is from 700 to 730 cubic feet of hydraulic lime, and 160 to 180 maunds (maund equal to 2¼ cubic feet, measured after slaking) of rich lime.

The quantity of lime stone required for the vaulting is from 260 to 290 cubic feet, measured as stacked in heap.

After the burning, the hydraulic lime may be slaked for use in the same manner as ordinary lime. If kept a little time, however, the balls fall to powder, more or less from exposure to the air, but the lime will keep good in this way for some weeks, or even months. It is necessary, however, to store the lime under shelter in a closed shed.

The lime prepared under the foregoing process, set under water in from 24 to 48 hours, and appears in every way to fulfil the conditions of an eminently hydraulic lime, as defined by M. Vicat.

106. *Details of cost of manufacture of one kiln yielding about* 700 *cubic feet* :—

N.B.—The lime measures about the same in cubic content whether in balls or after having fallen into powder.

Particulars.	Description.	No.	Rate.	Per	Amount.	Total.	Percentage.
MATERIALS.					R. A. P	R. A. P.	
Rich lime,	Maunds, Cubic ft	362 815	1 0 0	mds. 2½	144 12 9		
Limestone for base of charge, ...	Cubic ft	290	6 4 0	c ft. 100	18 2 0		
Water (fresh) for slaking lime, obtained from base of charge, ...	Gallons,	900	0 5 0	galls 100	2 13 0		
Labor for slaking and measuring lime obtained from base, ...	Laborers, " Boys, "	21 1 6 4	0 6 0 0 7 0 0 3 6 0 3 0	diem, " " "	7 14 0 0 7 0 1 5 0 0 12 0		
					176 1 9		
Deduct value of rich lime obtained from base of charge, ...	Maunds,	170	1 0 0	mds. 2½	68 0 0	108 1 9	24 70
Carried over, ...	...	...	...	...	...	108 1 9	24 70

Particulars.	Description.	No.	Rate.	Per.	Amount.	Total.	Percentage.
					R. A. P.	R. A. P.	
Brought over, ...	...	..	...	..	...	105 1 9	24·70
Clay, ...	Cubic ft.	148	6 0 0	c. ft. 100	8 14 0	8 14 0	2·05
Water (fresh) for mixing lime and clay, . .	Gallons,	1,600	0 5 0	galls. 100	5 0 0	5 0 0	1·17
Firewood (babool), ...	Maunds, lbs.	330 31,160	1 0 0	mds. 2½	132 0 0	132 0 0	34·71
LABOR, MIXING LIME AND CLAY.							
Manual labor, ...	Laborer,	10	0 7 0	diem,	4 6 0		
	"	32	0 6 0	"	12 0 0		
	Boys,	7	0 3 0	"	1 5 0	17 11 0	4·05
Machinery charges for mixing by steam mortar mill,	...	...	..	...	40 11 0	40 11 0	9·30
Dividing the paste into balls, ...	Women,	38½	0 4 0	diem,	9 11 0	9 11 0	2·20
Loading kiln, ...	Laborers,	3	0 7 0	"	1 5 0		
	"	24	0 6 0	"	9 0 0		
	Women,	3	0 4 0	"	0 12 0		
	Boys,	5	0 3 6	"	1 1 6		
	"	6	0 3 0	"	1 2 0	13 4 0	3·04
Firing kiln, including removal of fire-wood,	Laborers,	8	0 7 0	"	3 8 0		
	"	12½	0 6 0	"	4 9 0	8 1 0	1·85
Drawing kiln and storing lime, ...	Laborer,	12	0 7 0	"	5 4 0		
	"	23	0 6 0	"	8 10 0		
	Women,	1	0 4 0	"	0 4 0	14 3 0	3·21
Foreman lime burner, ...	...	Days 20	1 0 0	"	20 0 0	20 0 0	4·57
						397 11 9	90·91
Add for depreciation of, and repairs to kiln, lime sheds, tools, and charge for service ground occupied in drying balls, ..	...	...	10 0 0	per c. ft.	...	39 12 4	9·09
Total cost of 700 cubic feet of lime, ...	...	...	...	...	...	437 8 1	100·00
Cost of one cubic foot, ...	...	...	...	...	...	0 10 0	...

NOTE.—The cost of the hydraulic lime at Roree in 1858 was about 2 annas per cubic foot, but there, labor was only about one-third, and firewood one-fourth Kurrachee rates; also stone clay and water were procured on the spot at nominal cost, while all these materials have to be brought from a considerable distance at Kurrachee. Such lime now costs at Roree about 3 annas 7 pies per cubic foot, or 1 rupee for 2 maunds.

107. Perpetual kilns.—*Figs.* 1 and 2, are given by M. Vicat as sections of the best forms of perpetual kilns, the fuel used being coal; the small conical erection shown in section, in *Fig.* 1, being intended to give the lime a direction in falling through the orifices. The out-turn of the former is 241·5 cubic feet, and of the latter 158·1 cubic feet of lime per day.

Fig. 1.

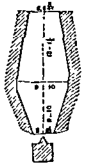
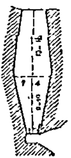
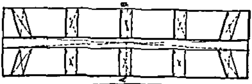


Fig. 2.



108. *Madras kilns.*—*Figs.* 3 and 4, are a plan and cross section of the kilns generally used in Madras. The lime is made of shells, which are mixed up with about half their bulk of pieces of charcoal. A small arch runs longitudinally through the kiln, covered with a grating of brick-on-edge, and partially strewed with broken tiles. On this is placed a layer of charcoal about 3 inches thick, and the kiln is lighted. The mixed shells and charcoal are then laid in small heaps about 18 inches apart and when the fire has reached them, the space between is filled up. When the fire has extended to them also, another layer is laid, and so on till the kiln is filled.

Fig. 3.



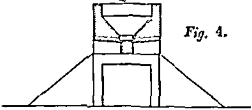


Fig. 4.

The transverse arches are to promote the current of air, the windward one being always open, and the other closed. The shells take 12 hours to calcine, and 24 hours more to cool sufficiently to be taken out. A kiln of this size holds about 90 cubic feet of shells.

The Sylhet lime, which supplies Calcutta, is burnt in a very similar way, in round kilns containing about 700 maunds. Reeds and dry wood are used for fuel.

109. The natives of this country frequently burn lime without a kiln at all, laying it in alternate beds with dried cow-dung, and covering the whole in with a coating of mud to retain the heat.

The native method of lime burning without a kiln, possesses the two

great advantages of cheapness and simplicity. There is none of the expense of building a kiln, to which lime from all the neighbourhood must be brought, often at a considerable additional expense for carriage. But where the limestone is found, there it is burned; for there are few spots to which fuel cannot be rapidly taken. It is so simple a method too, and one so well known to the natives of the Upper Provinces, that the Engineer requires to give no instructions to the lime burner, but can generally get a contractor who will bring him good lime, at a moderate rate.

On the other hand, in this system of lime burning, there is a great waste of heat, and consequently of fuel; and often of lime too, so that it becomes quite worthy of consideration whether it would not be the truest economy, where any extensive works are to be built, to construct regular lime kilns, as they are built in England, and to burn the lime with the care and attention which is bestowed on it there. One undoubted advantage would be gained, that by making sheds and preserving the fuel from wet, lime might be burned in kilns, and consequently work carried on, all the year round hardly hindered by the rains; at least in the Upper Provinces. As it is, during the rainy months, lime burning generally ceases.

110. On Slaking Lime.—The methods employed for slaking lime have been generally divided into three heads. The first consists in throwing on the lime, as it comes from the kiln, enough water to reduce it to thin paste. Too much water is generally added, and the lime is "*drowned*," the slaking being checked. The second method of slaking, consists in flinging quick-lime into water for a few seconds, and withdrawing it before the commencement of ebullition. The operation is performed with baskets, into which the lime, broken into pieces about the size of an egg, is placed. After being taken out of the water, it is thrown into a heap, and allowed to fall to powder. This method of slaking has been found to be attended by various practical inconveniences, the chief of which is the difficulty of getting the workmen to hold the lime precisely the right time under water. The third process is called "air slaking," leaving the quick-lime exposed to moisture from the surrounding atmosphere. Although Vicat maintains that air slaking answers very well for fat limes, the majority of writers disagree with him; and it would be at all times an inconvenient and expensive mode of operation.

Treussart recommends a modification of the second method as the best. Instead of plunging the lime into water, he obtained a like result by

throwing a certain quantity of water on the lime. The lime was laid in heaps of about 10 cubic feet each, and the sand to be mixed with it after, placed all round it. The water was poured over it from tin-pots of known size, allowing of water about one quarter the bulk of the lime. The slaking was regulated by turning about in the lime an iron rod or shovel to keep it uniform, and then the lime was covered over with sand till the next day, when the slaking having become complete, it was mixed with sand in the desired proportions and the mortar used at once. Only as much being made over night as would suffice for the next day's supply.

111. Colonel Scott's directions for slaking hydraulic limes are very similar, viz.:—Sprinkle with water, cover up well with sand, keeping in the steam for at least 24 hours. The quantity of water varying from 2 to *6 gallons to the bushel, according to the kind of lime.*

112. It matters little whether pure limes be slaked in large or small quantities at once; but with hydraulic limes, only so much should be slaked at a time as can be worked off within the next 8 or 10 days. In order to make sure that the lime has entirely lost its affinity for water before being laid as mortar in the joints of a building, it is safer to leave hydraulic limes for from 24 to 48 hours after slaking, before making them into mortar. For want of this precaution, mortar has been known to expand and to burst even the heaviest masonry. Twelve to twenty hours are long enough for pure or feebly hydraulic limes; they should be left covered up during that time. Hydraulic limes should always be used as fresh as possible from the kiln, and as they slake with difficulty, they should be ground first, to ensure the operation being done perfectly. Hydraulic cements do not slake at all. They should be ground to fine powder and made into mortar either in a pug-mill or by hand in small quantities, being mixed with water only when required for use; taking care not to let them remain too long in that state, as they at once begin to harden. Generally the more hydraulic the lime, the less violent is the action caused by slaking it, and the less increment there is in the volume of the slaked powder.

113. On Forming Mortar.—In para. 97 it was attempted to confute the popular idea that the tenacity of lime is increased by mixing with it a certain proportion of sand. Sand is however generally mixed with lime, for the sake of economy; and for ordinary purposes, any good lime will stand the admixture without its properties being seriously impaired.

Theoretically, the most perfect wall is that in which the cementing material is just as strong as the brick or stone cemented. There is evidently no object in having the cement stronger; but up to the point of equal resistance, the strength of the whole wall will vary with that of the cement. Experience proves that with feebly hydraulic limes, $2\frac{1}{2}$ cubic feet of sand may be mixed with 1 cubic foot of lime, and the results will be a mortar of $\frac{1}{6}$th or $\frac{1}{7}$th the resistance of brick. With hydraulic lime of good quality, such as the lias lime of England, and many of the kunkurs of this country, $1\frac{1}{2}$ to 2 parts of sand may be used to 1 part of lime, but this is the limit. Scott's cement mixed with 4 parts of sand, and Portland cement with 5 parts of sand, attain as great a hardness as the ordinary bricks used in London, and this is probably about the limit which can be, or at least, which has been, obtained with any cement or mortar. For hydraulic works and foundations, equal portions of lime and sand should be the limit allowed.

114. In the Upper Provinces of India the most common mixtures for mortar are 1 part of stone lime to 2 of sand or soorkee; or 1 part lime, 1 part sand, 1 part soorkee. Kunkur lime will not in general bear any admixture of soorkee. Experiments made at Mean Meer in 1851 previous to building the new barracks, gave a mixture of 94 maunds of kunkur lime to 6 maunds of stone lime (without any sand or soorkee), as the best and strongest mortar that could be made of the materials then available, and this mixture was accordingly adopted. The price of the two was then Rs. 14 per 100 maunds for kunkur lime, and Rs. 1-2-0 per maund for stone lime, delivered on the works.

115. The qualities of lime and soorkee vary so much in different districts, that every Engineer should experiment for himself before commencing work in a new station; the practical facts deducible from the above paragraphs being, that in limes containing little or no argillaceous matter, such as that burnt from limestone boulders, an admixture of soorkee as well as of sand, will be advisable, especially for buildings exposed to wet; while in the case of kunkur or marl limes, little or no soorkee can be added without impairing their strength, as the necessary amount of clay is already present.

116. The following is an account of a remarkably fine kind of kunkur lime found at Belmurri, in the Gorruckpore District, which received the 1st prize at the N. W. Provinces Exhibition of 1867:—

Behmurri kunkur, so called from being found in a village Behmurri, Amorha pergunnah, zillah Bustee. It was first brought to my notice by some bricklayers. Shell lime being scarce and very dear in the districts, I gave some attention to this kunkur lime, which is so very different to the common kunkur used for roads and for mortar. The Behmurri lime was brought to my notice 20 years ago; it is to be found in veins running under the village on the banks of a small river called the Munwur, and stretching out into the adjacent land.

It is taken out by digging with the *kodah* in large blocks or clods, and is broken up by a mallet into small pieces, then laid out to dry. A circular kiln is raised about 8 or 10 feet high, the diameter at the base inside about 5 feet, slightly closing up to 4 feet at the top.

It has four or five open furnaces at the bottom for firing. It is usually burnt with charcoal, a layer of charcoal 5 inches deep, then a layer of kunkur in small bits, 6 inches deep, alternately, till the kiln is filled up; it is then fired, and the kunkur lime burnt in a dry state. It is then taken out, and put into small pits 5 or 6 feet square by 18 inches or 2 feet deep, the bottom generally laid over with bricks, water is then run into the pits, and the lime is slaked. It is left in this condition for a day or two, and the slaking over, it is well drenched in water: and then taken up and mixed with soorkee and made into mortar, with an addition of the common kunkur.

The Behmurri lime must *not* be mixed up in its dry state with soorkee, without being well drenched in water first, or its full qualities will not come to account. The bricklayers here generally used ⅓rd soorkee, ⅓rd Behmurri lime, and ⅓rd common kunkur lime, which makes a first rate cement; or ⅔rds soorkee and ⅓rd Behmurri lime will do excellently. The common kunkur lime serves much in the same way as sand in European mortar, for it has but poorly adhesive quality of its own. The Behmurri *kunkur* is found at the depth of about 6 feet, but an earth agglomerating with it commences to be found 3 feet from the surface. This earth is quite as good in its qualities as the full formed kunkur. Behmurri is 20 miles west of Bustee, and 25 north-east of Fyzabad, across the river Gograh on the Bustee side.

The Behmurri lime well drenched in pits with water, has a most adhesive property almost fully equal to shell lime, but must not be mixed up in mortar in its dry state; if about one maund of shell lime be put into the mortar pit with 10 maunds of Behmurri lime, the cement will be all the stronger, but of itself is quite good and strong for flooring, for plastering walls and cementing brick-work; in wall building it is first rate. For plastering and flooring work, it requires a good deal of beating, and ought to be kept during the process of plastering well wet and moist.

117. Colonel Sir Proby Cautley, an eminently practical Engineer, wrote as follows regarding mortars used in the Upper Doab:—

"The varieties of lime procurable between the Himalayas and Delhi are peculiarly favorable to hydraulic works. The beds of the rivers which drain the valley of Dehra, situated between the parent mountains and the Sewaliks, are loaded with boulders of lime rock; the single strata of the Sewaliks themselves contain also a plentiful supply; these, with the main outlets of the Jumna and Ganges, provide lime for all the upper portion of this Doab. The boulders are collected and either burnt on the spot, or carried to the works; in the former instance the cost of the material from the hills, to points between them and the town of Saharunpore averages as follows:—

			R.	A.
Cost per 100 maunds at the kiln from 8 to 10 Rs. say, ..	..	..	10	0
Carriage of ditto to the works at per md., 3 to 3½ annas say, ..		..	21	4
Customs levied at the ghâts or passes in the Sewaliks, say,	½ an anna per bullock load,	..	2	2
	Total cost per 100 mds.,	..	33	6

"Although this lime is in many cases pure, *i. e.*, crystalline carbonate without mixture—and by selecting the boulders previously to burning, may be obtained sufficiently pure for the whitest stucco, or white-wash—the article from the kilns is much adulterated with clays and metallic oxides, arising from the varieties of lime rock which are thrown into the beds of the rivers. With the use of soorkee therefore (or pounded brick), this lime makes an admirable water cement. In wells and foundations I have generally used it in the following proportions:—

2 parts soorkee
1 ditto lime, or

5 maunds, or 400 lbs. of soorkee,
1¾ maunds or 140 lbs. of stone lime.

mixed well together in a mortar mill before it is used. Above the level of the water I have found it advisable to reduce the quantity of soorkee; the cement in this case consists of

1½ parts of soorkee, or 3¾ maunds,
1 ditto of lime, or 1¾ maunds.

"The lime in fact is so good, that where well burnt bricks are used, bad masonry is entirely out of the question; the builder cannot help himself, and for this portion of his duty deserves no sort of credit whatever.

"This stone lime is used universally on the Doab Canal from the point where it leaves the Jumna to Rampoor, a town twelve miles south of Saharunpore, from this the marls and kunkur limes of the districts come into use, although the stone lime is brought into requisition on a smaller scale for arch-work as well as parapets; and in plastering masonry works it is solely used.

"The marl, or earth lime as it is usually called, is in much greater abundance on this line than kunkur. When extracted from the quarries or pits, it is perfectly soft and friable, in which state it is kneaded up into round balls about 2 or 3 inches in diameter, which are placed in the sun to dry, previously to their being burnt in the kiln. The marls differ very much in quality, but all of them make an admirable water-cement. That from Jussooe, a village on the khadir of the Hindun river, is the most approved of, and is delivered on the works within a circle of ten and fifteen miles at about 12 rupees per 100 maunds. These marls are full of fresh-water shells of species now existing in all the tanks, jheels, and rivers of the country; those of *melania*, *gymnæ*, *planorbis*, being the greatest abundance.

"The kunkur limes are more numerous in the southern districts of the canal, they also make a good water-cement, but contain no remains of fresh-water exuviæ.

"Near a village called Hursoroo, twenty-five miles to the south west of Delhi, a very superior kunkur lime is procured—the formation itself is intermediate between kunkur and marl, but the position of the quarries from which it is excavated is similar to that in which all this material is procured, in a low tract of country, the

site in all probability of a lake or jheel now filled up.* The same fresh-water shells as are found in the marls to the eastward of the Jumna, are very numerous in the Hursoroo lime. It is exported in large blocks, and is sold in Delhi at from twelve to fifteen rupees per 100 maunds. The cost after burning varies from twenty-five to thirty rupees per 100. This lime for a water-cement is very far superior to any lime that I have met with. When calcined it is of a very light color, and might be mistaken for the stone lime of the Northern Division. In the locks and works on the Doab Canal appended to them, at Shukulpoor, Sikrani, and Jaoli, in the southern district opposite Delhi, nothing but Hursoroo in the following proportions has been used in the superstructure :—

1 part of Hursoroo,
1½ ditto of Bujree, †

and in the neighbourhood of Delhi in the use of pounded brick, or soorkee has been almost entirely superseded by that of Bujree.‡

"The sand stone which is an attendant upon the great quartzose formation of the ridge upon which Toghlukabad, the Kootub Minar, and old and new Delhi stand, varies from compact and crystalline, to a loose and friable rock; in this latter case it consists of an agglutination of minute angular fragments of quartz, with, in some cases, a red oxide of iron in such abundance as to give the strata quite a peculiar character; in other cases the oxide is wanting, and this friable rock is of a light color. For roads and other purposes these varieties of the sand stone are much in request, and amongst the natives obtained the name of *Bujree*. Nothing could be a better substitute for soorkee, than the substance in question. The presence of the iron oxide is in every way favorable to its value in hydraulic works, and the sharpness of the particles of which it is composed renders it an admirable mixture with lime for plaster or stucco. In this form it stands the effect of the climate much better than soorkee or river sand. In the proportion of one part of Hursoroo lime to one part of bujree, mortar laid on with a float, as is used in sand, may be considered very far superior to it, and with a much better appearance than that practised by the natives, under the tedious process of beating with the *thappa*. This Bujree is now universally used on the Doab Canal works, at all points at which it can be delivered under eight rupees per 100 maunds, this being the maximum rate of pounded brick. For water-cement, the Hursoroo lime with a proper proportion of this red bujree may perhaps be considered as superior to all others attainable in this part of the world."

* Hursoroo is situated on a nullah which rises in the small hills near the Kootub Minar, and flows into the south-west end of the Furruknuggur jheel. The town of Hursoroo, or as it is more commonly called "*Hursoroo ghurree*," is about two miles from the *jheel*.

† The following is the detail of proportions used in the cement at these works, and as they were built in 1834-35, a sufficient time has elapsed to judge of the durability of the masonry, no repair of any description having taken place up to this period.

Foundations, including flooring, &c.,	Hursoroo Lime, ...	one	part.
	Earth lime, ...	two	"
	Bujree, ...	"	"
Superstructure, ...	Hursoroo Lime, ...	one	"
	Bujree, ...	one-and-a-half	"
Plaster, ...	Hursoroo Lime, ...	one	"
	Bujree, ...	"	"
Sandulla, or outer thin coating given to the plaster, as a finish,	Stone Lime, ...	eight	"
	Soorkee, ...	one	"

‡ This has, I believe, been the case in the Delhi works for many years.

118. There is much difference of opinion as to what sand is best suited for mixing with lime. Vicat concluded that the advantage of the three *different descriptions of sand employed by him*, varied with the nature of the lime. Others recommend sharp hard sand, not too fine; while Col. Totten found that sand as fine as powder, produce as good results as any.

The general opinion of writers has been, that pit sand is better than river sand, and sea sand is the worst.

It is probable that the difference of opinion on this subject may arise from the different kinds of lime that have been used. Fat lime will not harden if kept damp; and the presence of salt in the mortar will always keep it so. Hydraulic limes on the other hand harden all the better, though not so quickly, from being kept damp; and it is therefore reasonable to suppose that in either case, sea sand is not prejudicial. For internal plastering, sea sand is evidently unfit, on account of the moisture which keeps exuding from it, disfiguring its appearence, and making the room plastered, damp and unwholesome.

From the conflicting opinions on the subject of sand we may conclude—

1st. That in making ordinary mortar, our present knowledge and experience would not justify any great expense, in order to procure sand of any particular color or grain, or from any particular source. But that, generally, sand either too coarse or too fine should be avoided.

2nd. That for ordinary buildings we should, if possible, use river or pit sand in preference to sea sand. But if any great saving is effected by using the latter, we should not hesitate to do so; *taking the precaution* to wash it carefully first.

3rd. That for hydraulic building, sea sand is just as good as any other.

4th. That in all cases, *it is worth while to take pains to* clean the sand before using it, or to make sure that it is clean.

The great rule in mixing mortar is to see that the lime and sand be *thoroughly* and intimately amalgamated. According to some writers, continual working and beating is also essential to the making of good mortar; this, however, is doubtful. The ingredients may be mixed by hand or in a pug-mill, or what is best of all, under a wheel or stones revolving on edge.

119. It is common in this country to mix a small quantity of the coarsest sugar ("goor" or "jaghery," as it is termed in Madras), with the water used for working up mortar. Where fat limes alone can be procured, their bad qualities may be in some degree corrected by it, as its influence is very

marked in the first solidification of the mortar. Captain Smith attributes the fact, that mortars made of calcined shells have stood the action of the weather for centuries, to this mixture of "jaghery" in their composition. He made experiments on bricks joined together by mortar consisting of 1 part common shell lime to $1\frac{1}{2}$ sand. One pound of jaghery was mixed with each gallon of the water with which the mortar was mixed. The bricks were left 13 years; and after that time, the average breaking weight of the joint in 20 trials was $6\frac{1}{2}$ lbs. per square inch. In 21 specimens joined with the same mortar, but without jaghery, the breaking weight was $4\frac{1}{2}$ lbs. per square inch. In the jaghery mortars, the cohesion and adhesion were nearly equal; in the others the former was near double the latter.*

120. On Applying Mortar.—The first great point to be attended to in applying mortars, is the necessity of thoroughly wetting the materials to be joined; and this is a point too frequently neglected. If the moisture be suddenly drawn off any hydraulic mortar, it will not harden. Now, dry bricks and most stones absorb a large proportion of water, so that if mortar be applied to the dry surface of a brick and another pressed on it, the whole of the moisture will be squeezed out of the mortar and taken up by the bricks; and the mortar itself will crumble into powder. Whereas, if the brick be already thoroughly wetted, it will be able to absorb no more moisture, and the mortar will set as it ought.

With many compact stones, such as granite, marble, &c., it will be sufficient to water the surface at the moment of using them. But porous materials, such as sandstone and bricks, should be allowed to soak in water for some hours before use. In a series of experiments on English bricks, weighing from $5\frac{1}{2}$ to 6 lbs., the average absorption of water was 12 oz. per brick; and some large bricks at Roorkee, weighing 11 lbs. when dry, were found to absorb 2 lbs. of water in 24 hours immersion. In a climate like that of this country, where there is so much evaporation, this point should be especially attended to.

The next requisite in applying mortar is, that the mortar should be as stiff as it can be used, without inconvenience, and without danger of all the unevennesseses of the joints remaining unfilled when the bricks are forced home.

The third requisite is to prevent rapid drying of the mortar after it has

* Professional Papers, Madras Engineers, Vol. IV.

been applied. This point has already been alluded to, and Table IV. gives the result of Vicat's observations on the subject.

121. Mortar which is exposed to the action of frost before it has set, is so much damaged as to impair entirely its properties. In building therefore, when the approach of frost is to be looked for, the foundations and the walls up to at least 3 feet above the ground, should be laid in hydraulic mortar, which will set rapidly; as the action of the frost is severest at the ground level. During severe frosts, all building should, if possible, be suspended. If the walls are very thick, the interiors will generally be protected from the cold, and it will be enough to lay and point the exterior joints with cement or superior mortar

122. Mortar is sometimes applied in a form termed *grouting*, that is, mixed with an excess of water, and poured liquid into the joints of the masonry. Colonel Raucourt de Charleville found that good grouting could be made of eminently hydraulic lime and fine sand mixed with water, and poured immediately into the joints, it hardened instantly without shrinking, and solidified all its water. Smeaton formed an excellent grouting of equal parts of lime and puzzuolana. Grouting is, however, not approved of by all Engineers. Col. Scott thus remarks of it—"If the joints of a work are not properly flushed up, undoubtedly grouting is of great advantage, especially when dry bricks are employed in work, but the strength of grout cannot at all compare with that of good stiff mortar; for grout when the water dries out, is merely very porous mortar, and the more fluid the grout, the weaker the work will be."

123. Concretes.—*Concrete* is a composition of small stones, bricks or rubble, and sand, with lime (ground to powder), generally in the proportions of from $\frac{1}{7}$th to $\frac{1}{8}$th of lime, to 1 of the mixture of rubble and sand. After the ingredients are thoroughly mixed, and water has been added, the concrete hardens into a solid mass.

124. Some authors draw a distinction between concrete and *béton*: regarding *béton* as being made with *hydraulic* mortar: and concrete prepared from non-hydraulic limes. Others again consider the difference to be in the mode of mixture: when the cement or lime is first mixed with sand, and treated as a mortar before being incorporated with stone or gravel, it is termed *béton*: and when that preliminary operation is omitted, it is called *concrete*. *Béton* may thus be said to be the French process, while *concrete* is the analogous but clumsy operation as orginally followed

in England. But such distinctions are too nice for practical purposes, and the names concrete and béton may be considered synonymous.

125. Concrete should not be made from rich limes, unless such are improved by being combined with powdered brick, puzzuolana, &c. If however circumstances compel the use of rich lime, it must be reduced to the finest powder by slaking or grinding, and evenly sifted through a very fine sieve: then mixed with a proper proportion of aggregate (gravel, sand, &c.), and wetted not over much, but sufficiently for its complete conversion into a hydrate. The rough process of taking rich lime fresh from the kiln, mixing it with the aggregate, and then wetting and turning over both together by manual labor, cannot so thoroughly effect *the reduction of the lime as to prevent the presence of large pieces of* it in an unslaked condition, which will eventually prove highly prejudicial to the mass of concrete. Such a mode of manufacture should not therefore be resorted to. The poor or hydraulic limes are better adapted for concrete purposes, in consequence of the amount of silica which they contain. They also require to be reduced to the finest powder by grinding or slaking (a No. 40 gauge sieve should be used). Such finely powdered lime, can be kept for a long time if packed in well made paper lined, barrels, guarded from the air, and kept dry.

126. In all concretes it is necessary to adjust the proportions of lime, sand and gravel, so that no vacuities will occur in the mixture. With an aggregate of an average size of 2 inches, it will be found that in every cubic yard, there will be vacuities equal to eleven cubic feet, so it is necessary that the mortar should be equal in quantity to that interstitial space. The results of experiments seem to show that the best results are produced when the size of the pieces of aggregate is a minimum. Major J. Browne, R.E., after building many arches, &c., of concrete on the Kangra valley roads, recorded his opinion that concrete in the form of *mortar* without stone, would be in the long run the best and strongest, but it would take much longer to set: and Mr. J. E. Tanner's experiments (for concrete arching on the Sirhind canal), appears to corroborate this view.* Coignet's *béton aggloméré* which has been used extensively for houses, churches, arches, *the Paris sewers, &c.*, is a *concrete in which no stone or gravel* is used, and the largest piece of sand is no larger than a pea. In the Thames embankment, it was made and used in the following manner:—

* Vide para. 130.

been applied. This point has already been alluded to, and Table IV. gives the result of Vicat's observations on the subject.

121. Mortar which is exposed to the action of frost before it has set, is so much damaged as to impair entirely its properties. In building therefore, when the approach of frost is to be looked for, the foundations and the walls up to at least 3 feet above the ground, should be laid in hydraulic mortar, which will set rapidly; as the action of the frost is severest at the ground level. During severe frosts, all building should, if possible, be suspended. If the walls are very thick, the interiors will generally be protected from the cold, and it will be enough to lay and point the exterior joints with cement or superior mortar.

122. Mortar is sometimes applied in a form termed *grouting*, that is, mixed with an excess of water, and poured liquid into the joints of the masonry. Colonel Raucourt de Charleville found that good grouting could be made of eminently hydraulic lime and fine sand mixed with water, and poured immediately into the joints; it hardened instantly without shrinking, and solidified all its water. Smeaton formed an excellent grouting of equal parts of lime and puzzuolana. Grouting is, however, not approved of by all Engineers. Col. Scott thus remarks of it—"If the joints of a work are not properly flushed up, undoubtedly grouting is of great advantage, especially when dry bricks are employed in work, but the strength of grout cannot at all compare with that of good stiff mortar; for grout when the water dries out, is merely very porous mortar, and the more fluid the grout, the weaker the work will be."

123. Concretes.—*Concrete* is a composition of small stones, bricks or rubble, and sand, with lime (ground to powder), generally in the proportions of from $\frac{1}{5}$th to $\frac{1}{8}$th of lime, to 1 of the mixture of rubble and sand. After the ingredients are thoroughly mixed, and water has been added, the concrete hardens into a solid mass.

124. Some authors draw a distinction between concrete and béton: regarding *béton* as being made with *hydraulic* mortar: and concrete prepared from non-hydraulic limes. Others again consider the difference to be in the mode of mixture: when the cement or lime is first mixed with sand, and treated as a mortar before being incorporated with stone or gravel, it is termed *béton*: and when that preliminary operation is omitted, it is called *concrete*. *Béton* may thus be said to be the French process, while *concrete* is the analogous but clumsy operation as orginally followed

it is intended to use thus artificial equivalents in the shape of burnt clays, or some such analogous mineral substance.

Roman cement from its quick setting properties is unsuited for use in concrete for ordinary house building, but owing to this very property, it is frequently employed in the preparation of concrete, where much running water in foundations prevents lime, or Portland cement, concrete from setting quickly enough for such works. It cannot be used with a large proportion of aggregates, and is therefore seldom used for general concrete purposes. When Roman cement is used, it should be powdered dry on to the aggregate, (1 part of cement to 4 of aggregate), and the mixture should be carefully wetted by a light spray of water; no ramming being allowed, as the action of the rammer would disturb the indurating action which speedily sets in.

In all cases where practicable, preference should be given to *Portland cement* concretes. The proportion of cement to aggregate varies very much. In the London main drainage works, where special excellence, regardless of cost, was aimed at, the cement of the finest quality was used with only 1 of sand to 1 of cement. In the sea forts of Copenhagen the following proportions were used:—

1 part Portland cement,
4 „ Sand,
16 „ Fragments of stone.

A very usual proportion for foundations is 1 part of cement to 10 of sand or gravel. In the absence of machines for mixing the material, the usual plan adopted is to spread the stones or gravel on a hard surface, and thoroughly saturate this aggregate; then upon these is spread a layer of the previously prepared mortar in the agreed proportions; the necessary amount of water is added and the whole mass then carefully mixed and turned with rakes and hoes, and then rammed incessantly with heavy iron rammers, until the mass is absolutely solid. But in large works it is now customary to perform the operation of mixing by machines. It must be borne in mind that when concrete is to be used in trenches, it should never be tipped from a height, but placed gently in position and carefully levelled. The old practice of throwing cement from a height was attended with injury to the mixture from the tendency of the larger pieces of gravel to detach themselves from the mass while being tipped.

Stone lime was used, and after being slaked with water, it was passed through an exceedingly fine sieve; the necessary quantity of Portland cement (a fluctuating quantity according to quality of the work and its cost) was added, with a fine sharp, clean river sand. The whole was then put into a specially constructed pug-mill, with the smallest quantity of water, and thoroughly amalgamated. From the pug-mill it was at once wheeled in barrows to the destined part of the work, and there spread in layers of about 6 inches deep, being carefully raked and slightly rammed. The works in question were executed during the winter, and although under such unfavorable circumstances, the centres upon which it was placed were struck in less than 14 days without any damage to the arches. The appearance of the work was pleasing, and closely resembled some varieties of Bath stone in texture.

127. Lime has been used in conjunction with puzzuolanas, trass, and pounded brick for concretes for a long period of time, more especially in works of a subaqueous character; but rich limes are more improved by such mixture than the poor or hydraulic ones; indeed in the case of the best poor limes it is unnecessary.

General Treussart recommends the following proportions by measure for béton:—

	For ordinary work.	For more important work.
Obernai quick-lime, ...	·30	·30
Sand, ...	·75	·55
Hydraulic cement,*	0	·20
Gravel, ...	·25	·25
Stone chips, ...	·50	·50

The béton was thus made in heaps of 1·80 parts, which on being mixed sustained a diminution of $\frac{1}{4}$th or $\frac{1}{5}$th their bulk. Each heap contained about 64 cubic feet of materials; the mortar was made first, and required 4 men to make it, the stones and gravel being added to it.

The following also are mixtures extensively used by him:—

	No. 1.	No. 2.
Hydraulic lime, very energetic, measured in bulk before slaking, ...	30	33
Trass from Andernach, ...	30	0
Puzzuolana from Italy, ...	0	45
Sand, ...	30	22
Broken hard limestone, ...	40	60

The first mixture required to be used at once, the second required exposure for 12 hours before being put in place.

These combinations are not of much practical value in this country, from the scarcity of the volcanic products, but will serve as a guide where

* *By Hydraulic cement*, Treussart appears to have meant trass, or puzzuolana, which was only added when there was not time for the lime to set before being exposed to wet.

have mentioned in the last para., as being the only legitimate field for the use of concrete. It has, however, been used for very different objects. Whole buildings have been constructed of concrete; sea and wharf walls, towers, church pillars, and even the piers and arches of bridges. It has been asserted that the pyramids of Egypt are built of artificial blocks of stone, composed of small stones and lime. The Romans used it for many of their great public buildings, such as the palace of the Emperors, the Colosseum, and many of their aqueducts and theatres.

Treussart considers concrete admirably adapted for all works where dryness or water-tightness are of consequence, such as grain-cellars, magazines, casemates, aqueducts, &c.

Concrete may be thus used, either by making it in moulds into great artificial blocks of stone, and using them when hardened, as ordinary large stones are in masonry; or walls may be built of fresh concrete rammed tight between frames, like Pisé work. One very strong argument in favor of block making, is the advantage of ascertaining the quality of the concrete before it is placed in position; an advantage not secured by frame building, which necessitates the uninterrupted continuance of the work, which if executed with a bad quality of cement, would entail heavy loss. The quantity of cement required for blocks is less than that which must be used in the monolithic mass.

The Italians made concrete blocks 4 feet 8 inches × 2 feet 8 inches, which, after being buried under ground for 2 or 3 years attained great hardness, and were used in the angles of the fortifications of Alessandria.

130. *Concrete arches.*—Near Barcelona, is a bridge consisting of 2 rows of arcades placed one on another, 150 feet high, and 700 feet long, composed entirely of concrete At Grisoles, in the South of France, a canal bridge was built of the same substance (2 parts hydraulic lime to 3 parts of sand, and 5 parts of gravel stones) of $39\frac{1}{3}$ feet span, $5\frac{1}{4}$ feet rise, and $19\frac{2}{3}$ feet broad. The abutments, spandrels, arches, &c., were all of concrete; the only exception being that the corners of the abutments, beneath the bridge, were faced with stone to receive the rubbing of the towing ropes, and that the angles where the intrados meets the two faces of the bridge are of brick. The excavation of the foundations began June 15th, 1840, and the last piece of centering was removed from the structure on January 25th, 1841.

An experimental bridge arch of 75 feet span and $7\frac{1}{2}$ feet rise. made

128. Béton as used in France for subaqueous work is generally made and lowered into the water in a box, so constructed that it can be opened, and its contents discharged by pulling a cord, so as to deposit the béton on the bottom without allowing it to fall through a depth of water which might wash away the lime. The box should be lined with a casing of tarred canvas, a large bag in fact, which remains round the béton after the box has been removed. Sheet piling ought to be built all round to protect the fresh work from the action of the water, as this is quite essential. In India, béton has been much used in filling in the well cylinders forming the piers of so many of the Railway Bridges, the béton being lowered in an iron *skip*, which, on touching the bottom, opens out and discharges its contents.

Béton has been employed on a very large scale by the French in the harbour works at Algiers. Masses were sunk in caissons lined with tarred cloth of from 2,000 to 6,000 cubic feet each. Blocks also as large as 1,765 cubic feet, were made in moulds on the shore, and sunk after being set. The composition of the former was, 1 part of rich lime to 2 parts of Italian puzzuolana. For the blocks set on shore, sand was mixed in equal quantities with the puzzuolana. The point was fully established at Algiers that blocks of béton have sufficient strength to resist the heaviest seas without injury, and that they form an indestructible mass. These blocks were found immovable when above 353 cubic feet in size. M. Poirel has thus summed up the advantages of this style of subaqueous foundation—"1st, Immediate stability whilst ordinary rubble work is never secure; 2nd, Incomparably greater facility in the carriage of materials, generally so troublesome and expensive when blocks have to be quarried exceeding 100 cubic feet; 3rd, A considerable reduction in the sectional area of the pier, and consequently a remarkable saving of cost; 4th, That the system is everywhere applicable, now that our advanced knowledge of the subject of hydraulic mortars enable us to make béton in every locality."*

129. Engineers often look on foundations, and such works as we

* Sir John Rennie does not consider, with M. Poirel, that submarine foundations of concrete or béton block are any better than those laid *pierres perdues*, that is, by throwing in blocks of stone at random. The question would then be which would be the cheapest; and this of course must vary with locality. At Algiers it appeared béton was cheaper than stonework; and it is very important to know that in such cases it would at least answer as well, if no better. See Rennie's "Treatise on Harbours."

abutting block, (as shown in sketch), and the mortar of the concrete works up. The best results in his experiments were obtained from the following ingredients—1 lime, 2 sand, 4½ stones, the sand being pure washed river sand, composed chiefly of granite particles, the lime being from boulder lime stones, and the stone broken granite; soorkee however in the concrete while delaying the *hardening*, gave more *tenacity* than obtained from sand: broken arches giving slowly and seeming to tear; while those built with sand often during his experiments broke at once without giving a sign. These Kangra valley concrete arches, when 8 feet in span, and 1 foot thick at crown, bore before breaking 1,863 lbs. per square foot of roadway.

With a view to deciding as to the advisibility of using concrete monolithic arches for the superpassages of the new Sirhind canal, experiments were made by Mr J. E. Tanner, C.E., on concretes formed of stone lime from the Punjab hills, kunkur lime from Loodiana, Sutlej river sand, and brick broken small to pass through ¾ inch rings. With these materials a brick arch 45 feet span, 3 feet thick at crown, was built as a sample for bridges; and a roof 9 inches thick at crown, 1 foot rise, and 15 feet span was built of concrete, composed of 1 part of stone lime, 1 part kunkur, 3 parts brick gravel. The latter bore 380 lbs. per superficial foot before it broke. The results of the experiments showed that the concrete made of the *small* was undeniably stronger than that made with *large* material, and that the more it was consolidated, the stronger it became: also that the amount of water used very much effects the results, for if too much water be used, the concrete cannot be consolidated.

131. Concrete has also been used in building three and four-storied houses without crushing; so little has to be feared from it on that score. One great advantage about concrete structures is the cheapness with which they can be made. While modern art has very much facilitated almost all other kinds of work by the use of mechanical contrivances, brick-work still remains as completely as ever hand labor, requiring skilled workmen, and taking a long time to execute. Now, by substituting concrete for brick and stone masonry, we do away with this necessity for skilled and consequently expensive workmen; as any ordinary laborers can mix the

entirely of concrete, was a few years ago constructed over the Metropolitan Railway (London), and has proved quite successful. The concrete was $3\frac{1}{2}$ feet thick at the crown of the arch, increasing towards the haunches, which abut upon concrete skew-backs. The concrete was composed of 6 parts gravel to 1 of Portland cement, carefully laid in mass upon close boarding set upon the centering, and enclosed at the sides. The following is extracted from *Engineering* of 25th December, 1868.

"The amount of concrete employed in the bridge was about 4,800 cubic feet, which, weighing one hundred weight and a quarter per cubic foot, develops a gross weight of 300 tons from the structure alone. The centre of gravity in the half span being 16 feet 6 inches from the abutment, the weight of the same 150 tons, and the rise of the arch 7 feet 6 inches, the thrust at the crown is equal to 330 tons.

"*The arch being 3 feet 6 inches deep in the centre, and 12 feet wide, a* sectional area of 42 square feet is available to resist the thrust, which is consequently equal to 7 tons 17 cwts per square foot. The additional strain imposed upon the bridge per foot run for every ton of distributed load is equal to $2\frac{1}{4}$ tons per square foot, and the maximum strain for a rolling load, is about $3\frac{1}{4}$ tons per square foot, when the load is at five-eighths of the span

* * * * * * *

"From these trials, it is fair to assume that a thoroughly well-constructed arch of concrete is absolutely stronger than a similar one of brick ; but in practice the danger arises that it would be difficult to ensure, so high a quality of concrete as that employed in the present instance, and the proper supervision of the contractor's work by the engineer would be almost impossible in structures of this material, whilst the inspection of brickwork is an easy matter.

"The utter uselessness of inferior concrete was shown by *the failure of the bridge*, which was previously erected on the site of this present one, which yielded under its own load when the centres were struck ; whilst this, made with Portland cement *and laid with all the care the contractors could exercise*, was altogether a special piece of work. It is not, therefore, by any means to be inferred that it would be safe to substitute concrete for brickwork under ordinary circumstances ; but now we know that we can rely upon the material whenever exceptional conditions render its adoption expedient or imperative."

Major James Browne, R.E., when in charge of the Kangra valley roads, used concrete for the arches of all culverts up to 10 feet span, and built also a 40 feet span bridge of the same material. In the Kangra valley ordinary arch work cost from Rs. 20 to Rs. 40 per hundred cubic feet ; while the rate for concrete, for arches of any size amounts only to Rs. 9 per 100 cubic feet. Major Browne recommends that all arches should be *elliptical and not segmental ; as in a segmental arch the stones work* down from the ramming into the corner formed between the arch and the

abutting block, (as shown in sketch), and the mortar of the concrete works up. The best results in his experiments were obtained from the following ingredients—1 lime, 2 sand, 4½ stones, the sand being pure washed river sand, composed chiefly of granite particles, the lime being from boulder lime stones, and the stone broken granite; soorkee however in the concrete while delaying the *hardening*, gave more *tenacity* than obtained from sand broken arches giving slowly and seeming to tear; while those built with sand often during his experiments broke at once without giving a sign. These Kangra valley concrete arches, when 8 feet in span, and 1 foot thick at crown, bore before breaking 1,863 lbs. per square foot of roadway.

With a view to deciding as to the advisibility of using concrete monolithic arches for the superpassages of the new Sirhind canal, experiments were made by Mr J. E. Tanner, C.E., on concretes formed of stone lime from the Punjab hills, kunkur lime from Loodiana, Sutlej river sand, and brick broken small to pass through ¾ inch rings. With these materials a brick arch 45 feet span, 3 feet thick at crown, was built as a sample for bridges; and a roof 9 inches thick at crown, 1 foot rise, and 15 feet span was built of concrete, composed of 1 part of stone lime, 1 part kunkur, 3 parts brick gravel The latter bore 380 lbs. per superficial foot before it broke. The results of the experiments showed that the concrete made of the *small* was undeniably stronger than that made with *large* material, and that the more it was consolidated, the stronger it became: also that the amount of water used very much effects the results, for if too much water be used, the concrete cannot be consolidated.

131. Concrete has also been used in building three and four-storied houses without crushing; so little has to be feared from it on that score. One great advantage about concrete structures is the cheapness with which they can be made. While modern art has very much facilitated almost all other kinds of work by the use of mechanical contrivances, brick-work still remains as completely as ever hand labor, requiring skilled workmen, and taking a long time to execute. Now, by substituting concrete for brick and stone masonry, we do away with this necessity for skilled and consequently expensive workmen; as any ordinary laborers can mix the

ingredients and ram them down when mixed. This is not so much felt in India where manual labor is so cheap, as in Europe; although here too, in many cases of extensive works, much money might probably be saved by it. It was recommended to be used for the projected weir across the Ganges, by the Ganges Canal Committee in their Report of 1866.

It must be remembered, however, that artificial stones made of concrete must be protected from the frost until the mortar has thoroughly set; and generally speaking, concrete blocks appear eminently unsuitable for situations in which by constant collisions, pebble after pebble may be detached.

132. **On Plasters.**—It may be laid down as a principle that good masonry composed of well burnt bricks and good mortar, requires in general no plaster either to preserve or beautify it. A good builder will take pride in his brick-work, and will be sorry to see it covered up as an unsightly thing. This principle has been too much lost sight of in India, although there has been lately a great improvement in this respect; and the works on the Baree Doab Canal, on the Railways and elsewhere, show how little good masonry requires such embellishment. Many seem to attach the idea of want of finish to unplastered masonry. And some, who may be supposed not to object to the appearance of red brick and white mortar joints, yet believing implicity in the necessity of plaster, try to produce a pleasing effect by the contemptible *sham* of painting their plaster to look like brick work! There are, however, many cases in which it is quite legitimate to use plaster. If the building is not one of great importance, or if the masonry is not intended to be exposed to any unusual stress, the saving in India is so great by using underburnt bricks in place of "pucka" ones, or by using mud in place of mortar, that houses are constantly built of this description, and with such it is necessary to use plaster. Occasionally, too, buildings are so ornate that there is nothing more incongruous in plastering the outsides than in plastering the insides of ordinary houses. There are some beautiful examples of this in native architecture, as in Lucknow and elsewhere.

This is not the place to discuss whether it is true architecture to copy buildings from classical models, substituting bricks, and wooden lintels for massive blocks of stones. If it is, assuredly such buildings should be plastered. It would however be difficult to find any order or style of architecture, in its best days, intended to be carried out by plastered brick work.

Plaster should be used when there is any object in having the surface of the brickwork smooth; as in the case of a brick vault, or arched roof. If the outside were left unplastered, rain would penetrate through the finest joints; and in such a case plaster is employed, not so much to protect the masonry as to oppose a smooth surface instead of a rough one, for the water to run off. Lastly, in all common masonry, interiors of rooms, &c., are plastered.

133. Outside plaster in this country differs very little in its nature from ordinary mortar used in building. As, however, less strength is required of plaster than of mortar, it is usual to mix a larger proportion of sand or soorkee with the lime. The presence of the sand also, as stated in para. 97, is positively beneficial up to a certain point, as it diminishes the shrinkage of the plaster in drying. In England a much larger proportion of sand is generally used with the lime than in this country; probably because the lime is much more carefully made, and the ingredients more carefully mixed. As mentioned before, great caution should be used to mix plaster with *fresh* water, and *fresh* water sand only, as the presence of any salt will cause constant damp on the walls.

The following directions were given by Colonel Sir P. T. Cautley, relative to the plastering of the Solani aqueduct. The plaster as may be supposed from the materials used, is very good, but also very expensive.

1st. Plastering consists of three coats or layers, the first of which is called "choonah," and is composed of 1½ parts of stone lime to one part of soorkee, well mixed with *sunni* (hemp), cut in small pieces, and beat down with the mistree's wooden tapkee. This coat is laid on as thin as possible.

2nd. The second coating is called "sandullah," and is composed of 2 parts of stone lime to 1 part of soorkee, finely sifted, (but without the mixture of sunni,) to be laid on very thin, beat down a little and smoothed off.

3rd. The third coating is called "rung," and consists of 7 parts of best unslaked lime (*phool*) to 1 of the very best and reddish colored soorkee, finely sifted. This is put into a large earthen *nand* filled with water. it is then mixed up well with the hand, and strained through a fine cloth into common water handies, and allowed to settle for a few hours: after which the water on the top is removed, and the mixture at the bottom becomes the rung, which is laid over the plaster with a brush, and polished off with a raj mistree's little trowel or *kurnee*.

134. In England, when plaster is to be laid in two or three coats, much stress is placed on scratching the first coat while moist with a succession of lines crossing each other like trellis work, so as to form a rough surface to which the second coat may adhere. In this country plaster is generally consolidated by being patted for some time with a small wooden

trowel termed a "tapkee;" a long and tedious operation. For interiors it is sufficient to "float" the plaster, that is to lay it on very moist, and smooth it by passing a straight edge in different directions over its surface.

A common mixture for coarse plaster in English interiors consists of 3 cubic feet of mortar, made of equal parts of lime and fine sand mixed with 1 lb. of clean ox hair. For an upper coating, fine white lime mixed with a very small quantity of hair is used, without sand at all. The lime used is slaked with a great deal of water, and run out into a basin, where the water evaporates leaving a creamy paste.

135. Gypsum.—Wherever gypsum can be obtained easily in Europe, it is used exclusively for plaster. It is commonly termed "Plaster of Paris," as it is found in great quantities near that city. It is quarried in large blocks, burnt at a low heat, reduced to powder, and carefully protected from the air, as it absorbs moisture with great avidity; when mixed with water it increases in volume. The extent of the burning should be such that $\frac{3}{4}$ of the contained water should be driven off. If the gypsum be over-burned it becomes *anhydrous sulphate* which will not set again on addition of water. The proper degree of burning is between 212° and 272°. It is applied for the first coats very stiff, and more fluid for the last coat. Owing to its great solubility, gypsum is unfitted for external work.

The masons of Minorca use a cement made of gypsum, which they call "gueesh," for cementing together the cut stone with which they build; and in making partition walls, often reduce them to a thickness of four inches, by building them of small flat stones thus cemented. In India, gypsum is sometimes used for the fine joints of cut stone masonry; and, when very abundant, is occasionally mixed with sand in rubble masonry. It was largely used by the Mogul architects for the internal decoration of their buildings. When thus used at Agra it is called "guch." Although found in various parts of India, (as in the Dehra Doon,) little use is made of it in modern Indian architecture.

136. Stucco.—The name of *Stucco* is given to a species of plastering worked to resemble marble. It is generally made of lime, mixed with calcareous powder, gypsum, and various other substances; it becomes very hard and is capable of receiving a fine polish. The Italians lay on stucco in three coats; the first very coarse; the second finer, and forming a smooth even surface; on the top of which is laid the third coat, composed

of rich lime which has been very carefully and thoroughly slaked and passed through a sieve, mixed with pounded white marble; or sometimes, for interiors, with gypsum.

The different colors are obtained by mixing with the lime certain metallic oxides; as for instance, to obtain a blue, 2 measures of marble powder, 1 of lime, and ½ measure of oxide or carbonate of copper is used. To obtain green, green enamel is mixed with the marble powder. Grays are produced by a mixture of ashes with the marble. Blacks by using forge ashes containing particles of iron. Litharge, or calcined ochre, gives a red; yellow oxide of lead gives yellow. The mixtures thus obtained are subsequently laid on in patches, and the excellence of the work consists in the taste with which they are employed to imitate marble. When the stucco is perfectly dry, polishing is begun. The surface is rubbed with a very fine grained stone, washing and clearing it with a sponge. It is then rubbed with a linen cloth containing moistened Tripoli powder and chalk; then with oil and Tripoli powder, and lastly with oil alone

137. *Chunam.*—Madras "chunam" is a very fine stucco. It is laid on in three coats: the first a mixture of shell lime and sand, tempered with jaghery water,* about half an inch thick; the second made of sifted shell lime and fine sifted white sand without jaghery, as it would color the plaster. The third coating which receives the polish is prepared with great care; the finest and whitest shells being selected for the lime, and mixed with from one-fourth to one-sixth their volume of the finest white sand. The ingredients of the second and third coat are ground with a roller on a granite bed to a smooth uniform surface resembling white cream. In about every bushel of this paste are mixed the whites of 10 or 12 eggs, half a pound of "ghee" (clarified butter), and a quart of "dahee" (sour curded milk), to which is occasionally added from one-fourth to one-half a pound of powdered soap-stone, which is said to improve the polish. These ingredients vary, according to the opinion of the builder; the essentials in addition to the lime and sand, seem to be the albumen of the eggs and the oily matter of the gheo, for which oil is sometimes substituted. The last coat is laid on exceedingly thin, and before the second is dry; it dries speedily, and is afterwards rubbed with the smooth surface of a piece of soap-stone, or agate, to produce the polish, sometimes for

* Water containing a solution of coarse sugar.

many hours. Water continues to exude from the plaster for several days, which must be wiped off.

138. White-wash.—The interior walls of Indian houses, as also in some cases the exterior, are generally *white-washed* in lieu of being painted or papered. "White-wash" is merely a thin solution of slaked lime with some ingredient, as gum, glue, or rice water, to render it adhesive to the walls. The white-wash should be *of such consistence that it will not* immediately drop from a brush dipped into it, and should be mixed with sufficient size or rice water to ensure its adhering to the wall and not being rubbed off by any thing brought into contact with it.

Before white-washing an old wall, the former coat of white-wash should be scraped off, or else the new coat will not adhere properly.

For 100 superficial feet of ordinary white-wash are required $1\frac{1}{2}$ seers of stone lime and ·05 chittacks gum.

The following, however, is a recipe for a superior description of white-wash, which will withstand a heavy down pour of rain, and is suitable for exterior surfaces.

White Lime—40 seers, slaked with hot water in a covered vessel.

Salt—5 seers, dissolved in hot-water.

Coarse Rice—3 seers, pounded and boiled to a thick paste. (*Kanjee*).

Glue—$\frac{1}{2}$ seer, dissolved in hot-water and the dirty refuse rejected.

These ingredients should be mixed, stirred, and diluted with hot water, till the consistency becomes that of ordinary white-wash.

The mixture should then be allowed to simmer for a few hours over a fire; it should next be strained, and finally laid on to the walls *while hot.*

N.B.—The above amounts should suffice for 2,500 superfical feet of wall surface.

Another recipe for white-wash is given on page 215; and the directions given, on page 214, for *distemper* apply equally for white-wash.

CHAPTER V.

TIMBER.

139. *Timber*, derived from the Saxon word *timbrian*, to build, is the term for wood of a size sufficient to be adapted to Building or Engineering purposes, and is applied to no trees which measure less than 24 inches in girth. When the wood forms part of the living tree, it is called *standing timber;* when felled, it is called *rough timber;* after the log has been sawn into the various forms required, it is called *converted timber;* and the pieces are known as *sided timber*, *balk*, *thick stuff*, *plank*, or *board*, according to their shape and dimensions.

140. Structure.—All timber trees proper are *exogenous*, that is, they increase in girth by addition to their *external* surfaces of rings of young wood. Palms and tree-like grasses, such as bamboos, are *endogenous;* so called because, although the stem grows partly by the formation of layers of new wood on its outer surface, the fibres of that new wood nevertheless so cross and penetrate those previously formed, as to be mixed with them at one part of their course, and internal to them at another. The stems of endogenous trees, though light and tough, are too flexible and slender to furnish materials suitable for important works of carpentry.

The shape of a tree is usually eccentric, the annual layers being thicker at that side which has most air and sunshine, or towards which the roots have grown with most vigour, owing to the earth being softer or more nutritious in that direction.

The innermost part of the tree is called the *pith*, this is immediately enclosed by the *heart-wood*, which is the hardest part of the tree, and used for all durable works of carpentry. The outer and younger portion is called *sap-wood*. From the pith, thin partitions of cellular tissue, called *medullary rays*, extend towards the bark; between these are additional medullary rays which stretch inwards from the bark in the direction of the pith; rarely however, penetrating it. A tree is in fact, composed of a

soils. The best soils are those which without being too dry or porous, allow the water to escape freely, such as gravel mixed with sandy loam. The most injurious, those which are swampy and contain stagnant water, for they never fail to make timber weak and perishable. As to climate, the strongest timber—such as teak, iron-wood, ebony, and *lignum vitæ*, grow in tropical countries, surpassing in strength any produced in temperate climates; but of the same species of tree, that which is grown in the colder climate is the stronger. As instances, the red pine of Norway is stronger than that of Scotland, and the English oak than the Italian.

145. When timber is felled, the sooner it is removed from the forest the better. It should then be placed in a dry situation, and so that the air may circulate round it freely, but should not be exposed to the sun or wind. Squared timber does not split so much as round. It is an advantage when possible to set the timber upright, with its lower end a little raised from the ground. If this is not possible, it should be piled horizontally a little above the ground, with a free space for circulation of air between each piece; and when so raised, the supports should not be refuse wood, which infects the good timber, but made of cast-iron; when supports are not used, precautions should be taken to prevent the growth of vegetation around the logs, and the yard should be carefully drained.

146. Seasoning.—Timber is said to be *seasoned*, when by some process, either natural or artificial, the moisture contained in its pores has been expelled so far as to prevent decay from internal causes. *Natural seasoning*, which consists in exposing the timber freely to the air in a dry place, sheltered if possible from sunshine and high winds, is the best when time can be spared, as slow drying renders wood tough and elastic. Wood naturally seasoned, however, is only fit for carpenter's work after two years, and for joiner's work after four years' seasoning. Artificial methods have therefore been adopted, to effect it more rapidly. *Water seasoning*, the simplest of these, consists in immersing the timber in water as soon as cut. After a fortnight's soaking it is taken out and dried in an airy place. This plan, though rendering timber less liable to warp and crack, undoubtedly weakens it. It should be avoided, therefore, where great strength is required. If timber is cut when full of sap it benefits by this method, as the water removes the greater part of the fermentible matter

and makes the wood less liable to be worm eaten. Care should be taken that timber, when put in water, is entirely sunk, as partial immersion is most destructive. *Boiling* timber is another method. This in most cases impairs the strength and elasticity of timber, but causes it to shrink less. It is useful when joiner's work has to be executed in wood which takes a long time to season naturally. Timber should not remain long in boiling water or steam; four hours is generally sufficient. The drying after it is removed from the water should take place slowly. *Smoking* and *charring* timber is sometimes resorted to. It can only be done on a small scale, and if green timber is charred and then placed in the earth or in any unventilated situation, decay is sure to result, as the natural juices which are then confined to the tree, ferment, and produce dry-rot.

147. Dr. Paton, Post Master General of the N. W. Provinces, found boiling babool an excellent method of seasoning that wood. Besides seasoning it quickly, it gave it extra strength; wood thus prepared being found to suffer less, from an equal degree of wear and tear, than the same wood seasoned in the ordinary manner. Dr. Paton accounts for the good effect of boiling, by the fact that when boiled, the woody fibre is deprived of sap, and is saturated with the tannin which abounds in the bark of the babool tree. Green wood answers best for boiling, as it parts with its juices easily, and is easily impregnated with tannin. The bark should be fresh, and boiled along with the wood. After boiling, the wood should be placed for some days under cover, and free from a chance current of air. The rainy and cold seasons are the most favorable for the process. The average time required is four months; while the natural atmospheric process takes five years. Wheels made of wood thus prepared last four or five years.

148. The best method of artificial seasoning known, is Davison's *Desiccating Process*, which consists in exposing the timber in a chamber or oven to a current of hot air. This is impelled by a fan at the rate of 100 feet a second; the fan, air passages, and room, being so proportioned that one-third of the volume of the chambers is blown through it per minute. The moisture passes away by an opening in the roof. Samples of wood are weighed from time to time until it is found that the required proportion of weight has been lost. The best temperature of hot air varies with the kind and dimensions of the timber. Thus, for—

Hard-woods, in general, in logs or large pieces, ...	90° to 100°
Fir-woods, in thick pieces, ...	120°
" in thin boards, ...	180° to 200°

The time for drying varies with the thickness, thus—

Thickness in inches, ...	1, 2, 3, 4, 6, 8.
Required time, in weeks, ...	1, 2, 3, 4, 7, 10.

These periods are fixed on the supposition that seasoning takes place during *twelve hours only* of the twenty-four.

149. Timber lasts best when kept dry and in a well ventilated place. Wet timber is softened and weakened but does not necessarily decay, and some timbers which are comparatively useless in the air are exceedingly durable under water. The cotton tree is a remarkable instance of this. Alternate wetness and dryness, especially when accompanied by heat, soon destroys timber. For such situations, wood should be carefully selected and great precautions taken for its preservation. Slaked lime is a great destroyer of timber, which should, therefore, in buildings, be carefully protected from its contact. Teak and sál are the most durable Indian timbers and require little artificial means for their preservation.

Timber has to be preserved from moisture, from internal decay (the dry-rot) and from the attacks of insects; and in India where the white-ant abounds, this last is the most serious consideration. Oil paint preserves timber from the first, and the method of saturation by Kyan, Burnett, Payne and Bethell, from the second: Margary's and Bethell's processes, however, alone seem successful against the third. Kyan used corrosive sublimate (bi-chloride of mercury), a very expensive salt; Burnett, chloride of zinc; and Payne, first a metallic solution, and then a decomposing fluid, the capillary tubes being thus filled with an insoluble substance. Margary injects sulphate of copper, which being cheaper than mercury, can be used in a stronger solution. It is considered doubtful, however, as a preservative from dry-rot. Mr. Bethell's saturation of timber with creosote, a kind of pitch oil, is an effectual perservative in every way. It is effected by first exhausting the air and moisture from the capillary tubes, in an air-tight vessel, and then forcing in the oil at a pressure of 150 lbs. on the square inch, which is kept up for some days. Timber absorbs from one-ninth to one-twelfth of its weight of this oil.

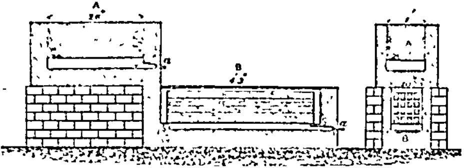
150. Major Sankey, R.E., applied Margary's process to a variety of

woods; the results of the experiments are appended in a tabular statement further on.

The accompanying figure shows the apparatus for steeping the wood.

A and B are teak wood troughs, hollowed from the solid tree; no metal joinings, therefore, interfere with the action of the solution.

A is the mixing, B the steeping, trough. It will be seen that 16 pieces are steeped each time.



aa, plugs and plug holes to each.

SS, steps for the ends of the bottom timbers to rest upon, while the small laths placed between each row permit the solution to circulate freely round the pieces.

All the specimens on arrangement are fastened down and kept in their proper positions by two pieces of twine passing through holes in the steps.

In the figure, the unshaded part represents the sulphate of copper (*neela-tutya*).

Having mixed, in A, the quantity of solution required, (the proportion being 1 lb. of sulphate of copper to 4 gallons of water, as recommended,) and secured the specimens in B, the plug *a* was withdrawn, and B filled as high as necessary. A small portion of solution was always reserved in A, to make up for the evaporation of B, which was thus kept filled to the proper height. According to the instructions, four days was the time the specimens should have remained in the solution (two days for each inch of thickness, but they were left five and a half and six days to prevent any mistake); when removed, the pieces were placed under cover to dry, and remained thus twenty days. The specimens thus prepared were buried in an ant-hill for several months, and the results of the trial are recorded in the following table.

TABLE OF EXPERIMENTS, BY MAJOR SANKEY, REFERRED TO ABOVE.

Names of woods	No. of each wood whose ends were sunk in the ant hill, March 1852.			Result of first trial in June, 1852				Result of second trial, in August, 1852.				Percentage of unsoaked pieces eaten in both trials, which will represent very nearly the liability of each wood to be attacked by insects.
				No. of soaked pieces.		No. of unsoaked. pieces.		No. of soaked. pieces.		No. of unsoaked pieces		
	No. of soaked pieces.	No. of unsoaked pieces.	Total.	Ant eaten.	Not so	Ant eaten	Not so.	Ant eaten	Not so.	Ant eaten	Not so.	
Arjoon,	6	4	10	...	6	...	4	...	6	...	4	...
Babool,	4	4	8	...	4	...	4	...	4	4	...	100 p. cent
Beja Sar,	10	6	16	...	10	1	5	...	10	6	...	100 p. cent.
Bhadah,	4	4	8	...	4	4	...	...	4	4	...	100 p. cent
Dhamin,	2	...	2	...	...	...	...	...	...	...	...	...
Dhareah,	4	4	8	...	4	4	...	...	4	4	...	100 p. cent
Dhaves,	4	2	6	...	4	2	...	...	4	2	...	100 p. cent
Eyne,	10	6	16	...	10	...	6	...	10	...	6	...
Hurdah,	10	6	16	...	10	6	..	...	10	6	...	100 p. cent.
Kaim,	4	4	8	...	4	4	...	...	4	4	...	100 p. cent.
Paunjerah,	4	4	8	...	4	4	...	2	4	4	...	100 p. cent.
Rohun,	8	4	12	...	8	...	4	..	8	2	2	50 p. cent.
Sál,	2	...	2	2	2	...	...	...	2	...	...	...
Siris,	4	4	8	...	4	2	2	...	4	4	...	100 p. cent.
Seesum,	10	6	16	2	8	6	...	2	8	6	...	100 p. cent.
Seesum,	4	4	8	...	4	...	4	...	4	1	3	75 p. cent
Teak,	10	6	16	...	10	...	6	...	10	...	6	...
Tendoo,	10	6	16	1	10	2	4	...	10	6	...	100 p. cent.
Thevus,	4	4	8	...	4	2	...	...	4	4	...	100 p. cent.
Thowra,	4	4	8	...	4	...	4	...	4	2	2	50 p. cent.
Toon,	2	...	2	...	2	...	...	...	2	...	...	...
Total, ...	120	82	202	5	116	37	43	4	116	59	23	73 p. cent.

Major Sankey remarks :—

"From the last column of the statement it would appear that *the three timbers*—teak, eyne and arjoon alone, of all those tested, in a natural state resist the attacks of insects. This is to a certain extent erroneous, for on particular examination, in respect to two or three timbers (as beja sar and seesum) having white wood, it seems that this *only is attacked, while the darker wood of the heart is left unassailed. In* the heart wood of beja sar (that portion always used) particularly, there is a quantity of red colored juice which exudes at every shower, and which is peculiarly obnoxious

to insects. The heart wood of seesum in like manner retains an essential oil equally distasteful to them.

"Panujerah, kaim, dharrah, and bhadah, were attacked with great avidity, and one or two of the unsoaked specimens of these woods perished *in toto*.

"The two pieces of seesum which were attacked, I have wrongly placed under the head of 'ant-eaten.' They were found on examination to be bored by a small beetle through the white wood.

"No specimen of dhamin was subject to the common insects; common report, however, makes it readily assailed by white ants.

"Hemp, rope, cloth, and some pieces of bamboo, which were steeped at the same time with the other specimens, were not attacked by white-ants.

"After removing from the ant-hill, washing and drying the specimens for the last time, I was much struck with the manner in which the atmosphere had acted on them severally; all those which had not been steeped, were weathered of the peculiar blueish gray color, so well known with unpainted timber after long exposure; while, on the contrary, the steeped specimens appeared nearly as bright and fresh as the day they were placed in the ant hill."

151. Measurement.—Timber is bought and sold by the cubic foot. If the log varies much in size in different parts, the length, breadth, and depth of these parts must be taken. If it tapers, a mean breadth or depth must be taken. In measuring rough logs, however, it is usual to gird the log at the measuring place, fold the girding string in four, and assume this fourth part as the side of a square at the measuring place. The area of this, multiplied by the length, gives the contents. Tables for every foot in length and quarter of an inch inside have been published, to facilitate the calculation. As less than 24 inches is not considered timber, in measuring standing timber, its height is the height at which the girth of the tree is 24 inches; the girth at half this height is taken as a mean. It is usual to speak of timber by the load, which in squared timber is 50, and in rough 40, cubic feet.

152. Indian Timber Trees.—The following lists contain the names of the most important trees in India, deserving the attention of the Engineer, either as furnishing timber to the carpenter and builder, wood for ornamental turnery, fuel for brick burning, sleepers for railways, or material for other purposes connected with Engineering works. A work of this description is of course no place for *complete* lists of all forest and other trees, and for botanical descriptions: which could not be given within the limits of a few pages, or even of a single volume.

For fuller details on such subjects, works specially devoted to Botany, Forestry, &c., must be consulted: and Balfour's "Timber Trees of India; Cleghorn's "Forests and Gardens of South India;" Skinner's "Indian and Burmah Timbers," may be advantageously referred to by those interested in Indian Trees.

But a brief list of the most important Indian trees, with co-efficients of weight, elasticity, &c., will be useful to every Engineer in the country, and may appropriately be embodied for reference in this work.

It will be observed that the first list contains the *Botanical* names which only are of real value, and precise application. *Local* names are in general very vague, and not to be depended upon: nor are they of any use beyond the limits of restricted areas. The same tree will be known by many different names over a tract of a few hundred square miles, and *it would tax the best memory to retain all the Indian local names of only* one or two trees, and correctly apply them to their own proper localities. Again, one local name may in one district refer to one tree, and in another district to a perfectly distinct plant. Thus the well-known name "Deodar" is applied in Cashmere, Huzara, Gurhwal and Kumaon to the *Cedrus Deodara:* in closely adjacent districts, (Koolloo and Kunawur,) to *Cupressus torulosa*; and in another neighbouring tract (Chumba), to *Juniperus Excelsa.* The Botanical name on the contrary has a precise application to one species of plant alone, and this not only in one country, but among all lands enjoying European civilization. Local names, however, are of course useful, and should be acquired by an Engineer in any district in which he may be employed. A list of a few such names follows the first "Botanical" list: but it must be remembered, that in many cases the identification of local names is very uncertain. *English* names are included in the "local" list; although few (so called) "English" names of Indian trees exist: and in their case also there is great want of precision. For example "Poon" and "Ebony" are terms loosely applied to a large *number of trees of many different "species," and even* "orders," and as names serving any useful purpose of precise identification are really valueless.

The numbers denoting weight, cohesive strength, &c., have been for the most part taken from the late Conductor Skinner's useful work on "Indian and Burman Timbers." The *precise* meaning of each separate

expression in these formulæ should be carefully realized, before using the formula.*

W denotes the weight *in lbs.* of a cubic *foot* of *seasoned* wood.

E_d is the co-efficient of *elasticity* as involved in Barlow's formula,

$$E_d = \frac{L^3}{bd^3} \frac{W}{\delta}$$

where E_d is a constant for each kind of wood, derived from experiment, and recorded in tables: L length in *feet*, b breadth and d depth both in *inches*, of a beam *supported* at the ends, and carrying at *centre* a weight W, in *lbs.* δ being the deflection at the centre in *inches* (*say* for timber $\frac{1}{480}$ of the clear bearing.)

f_t is the constant for each wood, denoting the direct cohesion in lbs. per square inch, and applicable to the formula,

$$P = A f_t$$

where P is the weight in *lbs.*, which would tear asunder a piece of timber whose transverse section has an area of A square *inches*.

p is the constant of strength in *lbs.* for timbers subjected to cross strain; and is applicable to the formula,

$$P = \frac{bd^2}{L} p.$$

Where P is the weight in *lbs.* at the *centre*, which would *break* a scantling *supported* at the ends having a clear bearing in *feet* = L, and a breadth = b, and depth = d both in *inches*.

These equations are constantly in use, as explained in the section on "Strength of Materials" in this Treatise, and the numbers given will be found useful for reference. Where more than one number is given for the same co-efficient, it will be understood that these are the results of different sets of experiments, carried out at different times and places, by different persons. In fact the same species of tree will furnish timber of very different quality, in different regions, and even in different parts of the same region: a fact which explains the extraordinary diversity in the statements and opinions recorded by different competent and reliable ob-

* In using this value of E_d, it should be borne in mind, that the E (= Modulus of Elasticity) Rankine's and Stoney's tables, (which co-incides also with F of Molesworth's elasticity tables) is 432 E_d of this formula; while Barlow uses two separate values of E (Elasticity), in his first tables the E = 1728 E_d, and in the second tables, his E = 64 E_d.

The modulus of rupture (f) of Rankine's tables is = 18p. of these tables while in Molesworth's tables, the co-efficient of transverse strength is 3p.

With these corrections, the values given in the tables alluded to can be used in these formulæ and comparisons instituted between the values of the English and other woods entered in those tables, and the values for Indian woods herein given.

servers: one authority describing a tree as lofty and furnishing large scantlings of fine timber: another alluding to it as a small tree supplying *no timber of any size or use.* So well known and valuable a tree as the *Deodar* will furnish an imperishable timber of immense scantling, if grown on some bleak northern granite slope of the inner Himalaya; while a comparatively soft and inferior wood is produced by the rapidly grown trees of moister forests on the lower slopes nearer the plains. It is advisable, therefore, for the Engineer to ascertain for himself the quality of each description of timber in the actual locality in which he himself is employed: to make experiments to determine its strength, &c., and be careful to utilize each sort properly: not to waste on some temporary structure a timber which may be a source of great value for some special purpose, while perhaps an inferior wood of no durability is being introduced in some important permanent building. As an example of this, Dr. Cleghorn relates how a small bridge, the total estimate of which was Rs. 250, was constructed of *Poon* spars, which while unsuited for this purpose, would have realized a very large sum for the Dockyards, where this timber is invaluable.

Avenues. It must be remembered that the Engineer is required not only to know the trees available in his district for providing timber, &c., for the purposes above indicated, but he may also have to plant *avenues* along roads and canals, and should acquaint himself with the trees best suited for such purposes, having regard to the nature of the soil, the amount of humidity, &c. In Northern India the best avenue trees, having green shady foliage almost throughout the year are, Nos. 4, 7, 18, 43, 54, 85, 86, 116 and 117, of the following list; where the usual rain-fall is 25 inches, these trees will thrive with the aid of rain only, after having been raised in nurseries and transplanted at the commencement of the summer rains to their positions at the road side, (where a "thala" should be prepared for each tree). Where, however, the rain-fall averages only 20 inches, it would be difficult to grow avenues of such trees without artificial irrigation, but the "keekar" might be successfully raised from seed sown in trenches where the trees are meant to remain.

In general, avenue trees should be raised in small nurseries, where the ground should be broken up to 15 or 18 inches in depth, and improved with leaf manure; the nursery being furnished with a well, if canal irrigation is not available.

LIST OF THE PRINCIPAL TREES OF INDIA.

N B.—*Trees marked * grow within 50 miles of Roorkee, N. W. P., either indigenous or introduced.*

No	W	E_d	f_t	p	
1	ABIES SMITHIANA. (*Coniferæ*)				A lofty spruce fir of the N W. Himalaya, dark and sombre, yet graceful with its symmetrical form and pendulous habit. It furnishes a white wood, easily split into planks; but not esteemed as either strong or durable. *It is used as 'shingle' for roof coverings.*
2	*ACACIA ARABICA. (*Leguminosæ.*)				
	54	4186 4111	16815	884 876	
3	*ACACIA CATECHU.				
	56 to 60				
4	*ACACIA ELATA.				
	39	2926	9518	695	
5	ACACIA LEUCOPHLÆA				This very thorny, white barked "keekur" is found in most parts of India, *and its timber in characteristics much resembles that of A. Arabica,* and is used for the same purposes.
	55	4086	16288	861	
6	*ACACIA MODESTA.				
7	*ACACIA SPECIOSA				
	55	3502 3332			is held to be brittle, and fit only for such purposes as box planks; and for firewood.
8	*ACACIA STIPULATA.				This unarmed, pink-flowered acacia, one of the largest of the
	50	4474	21416		
9	ADENANTHERA PAV (*Leguminosæ*)				
	56 55	3103	17846		rance somewhat resembling "sandal" wood. after exposure it becomes purple, like rose wood. It is used sometimes as sandal
10	AILANTHUS EXCELSA. (*Simarubaceæ*)				sequently, though useful for avenues, &c., where shade giving

No.	Name	W	E_a	f_t	p	Remarks
						trees are required to grow quickly, it does not furnish timber of any value. The wood is white, light and not durable; and is used for scabbards, &c.
11	ALBIZZIA ELATA. (*Leguminosæ.*)	42 to 55				Abundant on the banks of rivers in the Burmese plains. It is used by the Burmese for bridges and house posts; it has a large porportion of sap wood, but the heart wood is hard and durable, and in Dr Brandis' opinion, the wood may eventually become a valuable article of trade.
12	ALBIZZIA STIPULATA.	66				Grows in forests on elevated ground in Burmah; it has beautifully streaked brown heartwood, which is much prized for cart wheels and bells for cattle
13	ALBIZZIA *sp*	46	4123	19263	855	"Kokoh" is the Burmese name for an *Albizzia*, the wood of which is very much valued by the natives for cart wheels, oil presses and canoes It is a lofty tree, often having 60 feet of trunk before the first branch is thrown of.
14	ARTOCARPUS HIRSUTA. (*Artocarpaceæ*)	40	3905	15070	744	This large, handsome, shady tree grows in Burmah and South east India It yields the 'anjely' wood of commerce, especially esteemed as a timber bearing submersion in water. It is durable, and is much sought after for dock-yards as second only to teak for ship-building It is also used for house building, canoes, &c.
15	*ARTOCARPUS INTEGRIFOLIA	44	4030	16420	788	The common 'jack fruit' tree, is of rapid growth, and reaches a very large size It is found all over India, and is esteemed both for its fruit and timber, and with its abundant dark foliage and numerous pendent fruit is a handsome object. The wood when dry is brittle, and has a coarse and crooked grain. It is however, suitable for some kinds of house carpentry and joinery; tables, musical instruments, cabinet and marquetry work, &c. The wood when first cut is yellow, afterwards changing to various shades of brown
16	*ARTOCARPUS LACOOCHA.	40				The 'monkey jack' with its orange colored fruit is found usually as a cultivated plant near houses in India and Burmah. The wood is used in the latter country for canoes, the fruit is eaten, and a yellow dye is obtained from the root
17	ARTOCARPUS MOLLIS.	30				An immense tree on the hills of British Burmah, having an average length of trunk to the first branch, of 80 feet, and girth of 12 feet, 6 feet above ground The timber is used for canoes and cart wheels
18	*AZADARACHTA INDICA (*Meliaceæ*)	50	3183 2672	17450	720 752	The beautiful and well-known 'neem" tree, is common throughout India and Burmah, and is much esteemed for ornament and shade. It grows in the stoniest soil. The wood is hard, fibrous, and durable, except from attacks of insects · is of a reddish brown color and is used by the natives for agricultural and building purposes It is difficult to work, but is worthy of attention for ornamental woodwork. Long beams are seldom obtainable, but the short thick planks are in much request for doors and door frames of native houses, on account of the fragrant odour of the wood
19	*BAMBUSA (*Graminaceæ.*) (Plains) (Hills)		2801 5735		686 970	There are many distinct species of bamboo, all of which are applied to numerous useful purposes: bridge building, scaffolding, ladders, water pipes, rafts, roofing, chairs, beds, &c. [illegible] all sizes up to 60 feet in length [illegible] is the most generally [illegible] and experiments see[illegible] any other Indian wood. It is [illegible], being in reality a gigantic grass.
20	BARRINGTONIA ACUTANGULA. (*Myrtaceæ.*)	56	4000	19500	863	A large tree common to India generally and Burmah: 30 feet high; 4 feet in girth; flowers red. The wood of a beautifully red color, tough and strong, with a fine grain and susceptible of good polish. It is used in making carts, and is in great request by cabinet makers.
21	BARRINGTONIA RACEMOSA.	56	2815	17703	819	This tree is a native of Southern India, the Moluccas, &c.: and when in blossom is showy with its large rose-colored flowers.

No.	W.	l_s	f_c	P	

The wood is lighter colored, and close-grained, but of less strength than that of the last named species. It is used for house-building, and cart framing, and has been employed for railway sleepers.

22 *BASSIA LATIFOLIA (*Sapotaceæ.*)
| 66 | 3421 | 2?070 | 760 |

The "Mahwah" a well known Indian tree is in most districts preserved for its large fleshy flowers which are eaten and used in distilling arrack. The wood is, however, sometimes used for doors and windows and furniture but it is said to be eagerly devoured by white ants.

23 BASSIA LONGIFOLIA.
| 6? | 3174 | 15070 | 7?1 |

A common tree in Southern and Central India, esteemed for its edible flower and fruit, and the oil extracted from its seeds. For these reasons it is not commonly considered a timber tree, though in Malabar where it attains a large size, it is used for spars, and is considered nearly equal to teak though smaller.

24 *BAUHINIA VARIEGATA. (*Leguminaceæ.*)

This and other species of the genus are valuable, not for their timber, but as ornamental trees for avenues, &c., having beautiful conspicuous flowers. the centre wood is hard and dark like ebony, but seldom large enough for building purposes.

25 *BAUHINIA VAHLII

Some species of Bauhinia are scandent plants: and among the largest of these is the "Elephant Creeper" (a name applied also to *Argyreia serrata*) which destroys hundreds of valuable timber trees in the Sal Forests of Northern India, where one of the most arduous duties of the forest department is the eradication of these gigantic creepers whose cable like stems form festoons from tree to tree.

26 BERRYA AMMONILLA. (*Tiliaceæ.*)
| 50 | 2856 | 20704 | 781 |

"Trincomallie" wood is indigenous to Ceylon whence large quantities are annually imported into India; but the tree has also been introduced into South India. It is the most valuable wood in Ceylon for naval purposes and furnishes the material of the Madras Masula Boats. it is considered the best wood for capstan bars, cross trees, and fishes for masts. It is light, strong and flexible, and takes the place of *Ash* in Southern India for shafts, helves, &c.

27 BETULA BHOJPUTRA. (*Betulaceæ.*)

[illegible]
ble [illegible]
ha [illegible]
for [illegible]
Tibet, &c.

28 BIGNONIA CHELONOIDES. (*Bignoniaceæ.*)
| 48 | 2804 | 16637 | 642 |

This tree with its large fragrant, brownish orange colored flowers, is considered sacred by the Hindoos, and is consequently not largely available as timber. The wood is highly colored, orange yellow, hard and durable: a good fancy wood and suitable for house building. It is found in Southern India and Assam.

29 BIGNONIA STIPULATA.
| 64 | 5033 | 28998 | 1386 |

A flowering tree of the Tenasserim forests which furnishes long [illegible]

30 *BOMBAX HEPTAPHYLLUM. (*Bombaceæ.*)
| | 2225 | 6951 | 678 |

The large and stately Red "Cotton" tree is widely distributed [illegible] old trees.

31 BORASSUS FLABELLIFORMIS. (*Palmaceæ.*)
| 65 | 4904 | 11898 | 944 |

The Palmyra palm is inferior only to the Date and Cocoanut [illegible]

No.	W	E	f_1	p	
43	*CEDRELA TOONA (*Cedrelaceæ*)				
	31	2681 3368	9000		
44	CEDRUS DEODARA. (*Coniferæ*)				
		3365 2203 3925			the soil, and aspect of the place where it is grown.
45	CHICKRASSIA TABULARIS. (*Cedrelaceæ.*)				This is one of the trees named in commerce "*Chittagong*" wood, though occurring also in Burmah, Southern India and Eastern Bengal The wood resembles "Toon" in appearance and aroma,
	42	2876	9943	614	
46	CHLOROXLON SWIETENIA. (*Cedrelaceæ*)				
	60	4163	11369	870	
47	COCOS NUCIFERA. (*Palmaceæ*)				
	70	3605	9150		
48	CONNARUS SPECIOSA (*Connaraceæ*)				strong white timber, adapted to every purpose of house building.
49	CONOCARPUS ACUMINATUS. (*Combretaceæ*)				A large timber tree of Southern India and Burmah, where it reaches a height of 80 feet before the first branch, and a girth of 12 feet at 6 feet above ground The heart wood is reddish brown, hard and durable, used for house and cart building. If exposed
	59	4352	20623	880	
50	*C				is more Dehra wood, very strong in sustaining cross strain In Nagpore 20,000 axle trees are annually made from this wood. It is well suited for carriage shafts
51	CUPRESSUS TORULOSA. (*Coniferæ.*)				This is a handsome lofty tree of the North West Himalaya; but is not at all abundant and being esteemed as sacred (and termed 'dewadara' (deodar) or "god timber" in some hill states) it is not felled or made generally available as timber, though
52	DALBERGIA LATIFOLIA. (*Leguminosæ.*)				
	50	4053	20283	912	
53	*DALBERGIA OOJEINENSIS.				wheels, and ploughs.

No. | W | E_a | f_t | p |

54 *DALBERGIA SISSOO

| 50 | 4022 | 21257 | 807 |
| | 3516 | 12072 | 706 |

There is scarcely a tree in India which deserves more attention than the *Sissoo*, taking into account its beauty and uses, and its rapid growth in every soil. It is said to attain perfection in 28 years. It is widely spead through Northern and Central India, and is more used than any tree for avenues along roads and canals, and for planting in Cantonments. It furnishes the Bengal Gun-carriage agencies with their best timber, and is the best of all Indian woods for joiner's work, tables, chairs and furniture.

55 DILLENIA PENTAGYNA (*Dilleniaceæ*)

| 70 | 3650 | 17053 | 907 |

A stately and valuable forest tree of Southern India and Burmah, furnishing some of the *poon* spars of commerce. The wood is used in house and ship building, being close-grained, tough, durable, (even under-ground,) of a reddish brown color, not easily worked, and subject to warp and crack.

56 *DILLENIA SPECIOSA.

| 45 | 3355 | 12691 | 721 |

The *Chulta* is a large and ornamental tree of India and Burmah, with large fragrant white flowers, edible fruit, and light, strong, light brown wood of the same general characteristics with the preceding tree. It is used in house building and for gun stocks.

57 DIOSPYROS EBENUM (*Ebenaceæ*)

The true *Ebony* tree grows in Ceylon and Southern India. This heart wood is deep black, the outer wood is white; with advancing age the black wood increases. It is much affected by the weather, so that it is seldom used, except in veneer, and delicate and costly cabinet work.

58 DIOSPYROS HIRSUTA

| 60 | 4296 | 19830 | 757 |

A middle sized tree of Ceylon and Coromandel, furnishing one of the *Calamander* woods of commerce, of a chocolate color, with black streaks and marks, esteemed for ornamental purposes: scarce and valuable. Obtainable in logs 12 feet long, 4 feet in girth.

59 DIOSPYROS MELONOXYLON

| 81 | 5078 | 15873 | 1180 |

This is a very large tree of South India and Pegu, furnishing a valuable wood for inlaying and ornamental turnery, the sap wood white, the heart wood even grained, heavy, close and black, standing a high polish.

60 DIOSPYROS TOMENTOSA.

This is the North Indian representative of the ebony-producing Southern forms of Dyospyros occurring in Northern Bengal, Oudh, &c., a tall elegant tree, furnishing a hard and heavy black wood. The young trees are extensively felled by the natives as cart axles, for which they are well suited from their toughness and strength.

61 DIPTEROCARPUS ALATUS. (*Dipterocarpaceæ*)

| 45 | 3247 | 18781 | 750 |

A magnificent forest tree of Pegu and the Straits, rising 250 feet in height, and 100 feet to the first branch. The timber is excellent for every purpose of house building, but if exposed to moisture is not durable: it is hard and coarse-grained, with a powerful odour, and of light brown color. It furnishes *wood oil*.

62 DIPTEROCARPUS TURBINATUS

| 45 | 3355 | 16070 | 762 |
| 49 | | | 807 |

This is another lofty wood oil tree of Assam and Burmah, and the Andamans, with a coarse-grained timber of a light brown color, not easily worked, and not durable. It is used by the natives for house building, in sawn planks, which will not stand exposure and moisture.

63 *EMBLICA OFFICINALIS (*Euphorbiaceæ*)

| 46 | 2270 | 16964 | 562 |

The tree producing the *Myrobalan* fruit, is distributed throughout India, furnishing a hard and durable wood, used for gun stocks, furniture, boxes and veneering and turning: it is suitable for well curbs, as it does not decay under water.

64 *ERYTHRINA INDICA. (*Leguminosæ.*)

A common tree throughout India and Burmah, with a profusion of brilliant scarlet blossoms, whence it is called the "Coral" tree: it furnishes a soft, white, easily worked wood, being light, but of no strength, and eagerly attacked by white ants. It is used for scabbards, toys, light boxes and trays, &c. It grows very quickly from cuttings.

65 *EUCALYPTUS. (*Myrtaceæ.*)

This is not an Indian genus, but many species are now being naturalized in both the Hills and plains of India, imported from Australia. Sufficient time has not yet elapsed to establish the value of the "*Blue gum*" and other Eucalypti when grown in India.

No.	W	E	f_1	p	

66 *FERONIA ELEPHANT...
(*Aurantiaceæ.*)

| 50 | 3248 | 13909 |

house and cart building; and in some places employed as Railway Sleepers.

67 *FICUS ELASTICA.
(*Moraceæ.*)

The Caoutchouc fig tree grows on the Hills of Assam and Silhet, but is to be found as an imported tree in other parts of India. The milky juice is extracted by incisions across the bark down to the wood: 50 ozs. of the juice furnish 15 ozs. of Caoutchouc.

68 *FICUS GLOMERATA.

| 40 | 2113 / 2096 | 12691 | 588 |

69 *FICUS INDICA.

| 36 | 2876 | 9157 | 600 |

...est trees of India. Its wood is brown colored, light, brittle and coarse-grained, neither strong, or durable (except under water, for which cause it is used for well curbs.) The wood however of its pendent aerial roots is strong and tough, and used for yokes, tent poles, &c.

70 *FICUS RELIGIOSA.

| 34 | 2454 / 2371 | 7535 | 584 / 458 |

The *Peepul* is as widely spread and well known as the banyan, and with it is planted near temples and tombs, and in sacred groves. The wood is similar in appearance, characteristics and uses to that of the Banyan.

71 *GMELINA ARBOREA.
(*Verbenaceæ.*)

| 35 | 2132 | | |

A large forest tree ... a suitable tree for ... some flowers. It h... not shrinking or w... water: it is howev...

72 (*a*) *GREWIA ELASTICA.
(*b*) GREWIA TILIŒFOLIA.
(*Tiliaceæ*)

| 34 | 2876 | 17450 | 565 |

73 GUATTERIA LONGIFOLIA.
(*Anonaceæ.*)

| 37 | 2860 | 14720 | 547 |

The wood is very light and flexible, but is not used except for drum cylinders.

74 HARDWICKIA BINATA.
(*Leguminosæ.*)

| 85 | 4579 | 12016 | 912 |

An elegant, tall and erect tree of Central and Southern India, furnishing a red or dark colored, very hard, very strong and heavy wood, useful for posts, pillars, and piles and excellent also for ornamental turnery.

75 HERITIERA MINOR.
(*Sterculiaceæ.*)

| 64 | 3775 / 4677 | 29112 | 816 / 1312 / 925 |

This peculiar, gloomy looking, tree, known in Bengal as the "Soondree," grows on tracts occasionally inundated by the tides in Tenasserim and the Gangetic Delta, (giving their name to the Sounderbunds.) It is the toughest wood that has been tested in India, and stands without a rival in strength, and is used for piles, naves, felloes, spokes, and carriage shafts and poles. It is however a perishable wood, and shrinks much in seasoning.

76 HOPEA ODORATA.
(*Dipteraceæ*)

| 58 / 45 | 3660 | 22209 |

One of the finest timber trees of British Burmah, sometimes reaching 80 feet in height to the first branch, and 12 feet in ...

77 *INGA LUCIDA.
(*Leguminosæ.*)

No.	W	E	f	p

54 *Dalbergia Sissoo

50	4022	21257	807
	3516	12072	706

There is scarcely a tree in India which deserves more attention than the *Sissoo*, taking into account its beauty and uses, and its rapid growth in every soil. It is said to attain perfection in 28 years. It is widely spead through Northern and Central India, and is more used than any tree for avenues along roads and canals, and for planting in Cantonments. It furnishes the Bengal Gun-carriage agencies with their best timber, and is the best of all Indian woods for joiner's work, tables, chairs and furniture.

55 Dillenia Pentagyna (*Dilleniaceæ*)

70	3650	17053	907

A stately and valuable forest tree of Southern India and Burmah, furnishing some of the *poon* spars of commerce. The wood is used in house and ship building: being close-grained, tough, durable, (even under-ground,) of a reddish brown color, not easily worked, and subject to warp and crack.

56 *Dillenia Speciosa

45	3355	12691	721

The *Chulta* is a large and ornamental tree of India and Burmah, with large fragrant white flowers, edible fruit, and light, strong, light brown wood of the same general characteristics with the preceding tree. It is used in house building and for gun stocks.

57 Diospyros Ebenum (*Ebenaceæ*)

The true *Ebony* tree grows in Ceylon and Southern India. The heart wood is deep black, the outer wood is white; with advancing age the black wood increases. It is much affected by the weather, so that it is seldom used, except in veneer, and delicate and costly cabinet work.

58 Diospyros Hirsuta

60	4296	19830	757

A middle sized tree of Ceylon and Coromandel, furnishing one of the *Calamander* woods of commerce, of a chocolate color, with black streaks and marks esteemed for ornamental purposes: scarce and valuable. Obtainable in logs 12 feet long, 4 feet in girth.

59 Diospyros Melonoxylon

81	5058	15873	1180

This is a very large tree of South India and Pegu, furnishing a valuable wood for inlaying and ornamental turnery, the sap wood white, the heart wood even grained, heavy, close and black, standing a high polish.

60 Diospyros Tomentosa

This is the North Indian representative of the ebony-producing Southern forms of Diospyros: occurring in Northern Bengal, Oudh, &c., a tall elegant tree, furnishing a hard and heavy black wood. The young trees are extensively felled by the natives as cart axles, for which they are well suited from their toughness and strength.

61 Dipterocarpus Alatus (*Dipterocarpeæ*)

45	3247	18781	750

A magnificent forest tree of Pegu and the Straits, rising 250 feet in height, and 100 feet to the first branch. The timber is excellent for every purpose of house building, but if exposed to moisture is not durable: it is hard and coarse-grained, with a powerful odour, and of light brown color. It furnishes *wood oil*.

62 Dipterocarpus Turbinatus

45	3375	15070	762
49			807

This is another lofty wood oil tree of Assam and Burmah, and the Andamans, with a coarse-grained timber of a light brown color, not easily worked, and not durable. It is used by the natives for house building, in sawn planks, which will not stand exposure and moisture.

63 *Emblica Officinalis (*Euphorbiaceæ*)

46	2270	10961	562

The tree producing the *Myrobalan* fruit, is distributed throughout India, furnishing a hard and durable wood, used for gun stocks, furniture, boxes and veneering and turning: it is suitable for well curbs, as it does not decay under water.

64 *Erythrina Indica. (*Leguminosæ.*)

A common tree throughout India and Burmah, with a profusion of brilliant scarlet blossoms, whence it is called the "Coral" tree: it furnishes a soft, white, easily worked wood, being light, but of no strength, and eagerly attacked by white ants. It is used for scabbards, toys, light boxes and trays, &c. It grows very quickly from cuttings.

65 *Eucalyptus (*Myrtaceæ*)

This is not an Indian genus, but many species are now being naturalized in both the Hills and plains of India, imported from Australia. Sufficient time has not yet elapsed to establish the value of the "*Blue gum*" and other Eucalypti when grown in India

No.	w	E_d	f_t	p	
66 *FERONIA ELEPHANT... (*Aurantiaceæ.*)					
	50	3248	13909		
					Sleepers.
67 *FICUS ELASTICA. (*Moraceæ.*)					The Caoutchouc fig tree grows on the Hills of Assam and Silhet, but is to be found as an imported tree in other parts of India. The milky juice is extracted by incisions across the bark down to the wood: 50 ozs. of the juice furnish 15 ozs. of Caoutchouc.
68 *FICUS GLOMERATA.					
	40	2113 2096	12691	583	
69 *FICUS INDICA.					
	36	2876	9157	600	...est trees of India. Its wood is brown colored, light, brittle and coarse-grained, neither strong, or durable (except under water, for which cause it is used for well curbs.) The wood however of its pendent aerial roots is strong and tough, and used for yokes, tent poles, &c.
70 *FICUS RELIGIOSA.					
	34	2454 2371	7535	584 458	and ... gro... use...
71 *GMELINA ARBOREA. (*Verbenaceæ.*)					
	35	2132			
72 (*a*) *GREWIA ELASTICA. (*b*) GREWIA TILIÆFOLIA. (*Tiliaceæ*)					
	34	2876	17450	565	
73 GUATTERIA LONGIFOLIA (*Anonaceæ.*)					
	37	2860	14720	547	The wood is very light and flexible, but is not used except for drum cylinders.
74 HARDWICKIA BINATA. (*Leguminosæ*)					An elegant, tall and erect tree of Central and Southern India, furnishing a red or dark colored, very hard, very strong and
	85	4579	12016	912	heavy wood, useful for posts, pillars, and piles, and excellent also ...
75 HERITIERA MINOR. (*Sterculiaceæ*)					
	64	3775 4677	29112	816 1312 925	India, and stands without a rival in strength, and is used for piles, naves, felloes, spokes, and carriage shafts and poles It is however a perishable wood, and shrinks much in seasoning.
76 HOPEA ODORATA (*Dipteraceæ*)					One of the finest timber trees of British Burmah, sometimes reaching 80 feet in height to the first branch, and 12 feet in
	58 45	3660	22209	800 706	girth, a large boat of 8 feet beam and carrying 4 tons, being sometimes made of a single scooped-out trunk. The wood is close
77 *INGA LUCIDA. (*Leguminosæ*)					... Southern ... great height, ...y, foliage:

No. | w | E_0 | f_t | p

well suited for avenues. The heart wood is black, and is termed *Iron wood* in Burmah.

78 INGA XYLOCARPA

58 | 4283 | 16657 | 836

This valuable timber tree known as the *Iron wood* of Arracan is found throughout Southern India and Burmah, furnishing a wood of very superior quality, heavy, hard, close-grained, and durable, and of a very dark red color. It is, however, not easily worked and resists nails. It is extensively used for bridge building, posts, piles, &c, and is a good wood for sleepers, lasting (when judiciously selected, and thoroughly seasoned) for six years.

79 JUGLANS REGIA (*Juglandaceæ.*)

The *Walnut* is abundant in the villages of the N. W. Himalaya, and its beautiful wood is used for all sorts of furniture and cabinet work in the bazaars of the Hill Stations.

80 *LAGERSTRAEMIA REGINÆ (*Lythraceæ*)

40 | 3665 | 15358 | 637
41 | | | 642

This is a most beautiful flowering tree from South India, Burmah and Assam, but introduced into the gardens of North India for the beauty of its luxuriant purple blossoms. In Burmah it grows to a large tree, and the wood is used more extensively than any other, except Teak, for boat, cart, and house building, and in the Madras gun carriage manufactory, for felloes, naves, framings of waggons, &c

81 *MANGIFERA INDICA. (*Terebinthaceæ*)

42 | 3710 | 9518 | 632
| 3120 | 7702 | 560

The *Mango* is generally diffused over all the warmer parts of Asia, and is much esteemed for its fruit. Its wood, however, is of inferior quality, coarse and open grained, of a deep gray color, decaying if exposed to wet, and greedily eaten by white ants. It is, however, largely used, being plentiful and cheap, for common doors and doorposts, boards and furniture, and also for firewood. It should never be used for *beams*, as it is liable to snap off short.

82 MELANORRHŒA USITATISSIMA (*Anacardiaceæ*)

61 | 3016 | | 514

The *Varnish* tree of Burmah forms large forests in conjunction with Teak and Sál, and furnishes a dark-red, hard, heavy, close and even-grained and durable (but brittle) timber [illegible], sheave blocks, machinery [illegible]

83 *MELIA AZADARACH (*Meliaceæ*)

30 | 2516 | 14277 | 596

The "Persian Lilac" [illegible] India, Syria, &c, is orna[illegible] with sweet scented lilac [illegible] of leaves for many months [illegible] only its bunches of yellow 'beads', so that it is not altogether desirable as an avenue tree, though very much planted for this purpose. The soft, red colored, loose textured wood (resembling in appearance cedar) is used only for light furniture.

84 *MICHELIA CHAMPACA (*Magnoliaceæ*)

42 | | |

A fine timber tree with handsome foliage and flowers. In the Dehra Dhoon it reaches 16 feet in girth. In Mysore, trees measuring 30 feet in girth, 3 feet above ground level are found, and slabs 6 feet in breadth can be obtained; as the wood takes a beautiful polish, it makes handsome tables. It is of a rich brown color.

85 *MILLINGTONIA HORTENSIS (*Bignoniaceæ*)

A very handsome tree for avenues; tall and straight, with graceful foliage and fragrant white flowers. It grows very rapidly, but is not long lived, and is easily injured by storms. The bark is soft and spongy, the wood is white, fine and close-grained, but of little use.

86 *MIMUSOPS ELENGI (*Sapotaceæ.*)

61 | 3653 | 11369 | 692

This is an ornamental, more than a useful tree, grown in gardens and avenues throughout India and Burmah, for the beauty of its foliage, and its fragrant white flowers. The wood is heavy, close and even-grained, of a pink color, standing a good polish; and is used for cabinet making purposes, and ordinary house building.

87 MIMUSOPS HEXANDRA.

70 | 3948 | 19036 | 944

This tree grows in South India and Guzerat, and furnishes wood very similar to the last named, used for similar purposes; and for instruments, rulers, and other articles of turnery.

88 MIMUSOPS INDICA.

48 | 4296 | 23824 | 845

This is a valuable tree of South India and Ceylon; with a coarse-grained, but strong fibrous durable wood of a reddish brown color; used for house building, and for gun stocks.

No.	w	E_4	f_1	p

89 *MORINGA PTERYGOSPERMA. (*Moringaceæ.*) A handsome tall tree, with shady foliage, and of rapid growth. The wood is white and soft; and the scrapings from the root form a good substitute for the horse radish.

90 *MORUS INDICA. (*Moraceæ.*) This species of *Mulberry*, as well as *Morus Multicaulis*, and *M. Nigra*, are common in Northern India: in some parts of the Punjab and Oudh being planted in connection with silk worm rearing. It is also grown in avenues, for which, however, it is unsuited, being for many months quite bare of leaves. The wood is yellow, close-grained, very tough, and well suited for turning.

91 NAUCLEA CADUMBA. (*Cinchonaceæ.*) A noble ornamental tree of India and Burmah, with orange colored flowers, sometimes in the latter country, reaching 80 feet in height, and 12 feet in girth. It has a hard, deep yellow, loose-grained wood, used for furniture. In the Gwalior bazaars, it is [illegible]

92 *NAUCLEA CORDIFOLIA. [illegible] resembling in appearance Box, but light and more easily worked, and very susceptible to alternations of temperature. It is esteemed as an ornamental wood for cabinet purposes.

| 42 | 3032 / 3467 | 10431 | 664 / 506 |

93 *NAUCLEA PARVIFLORA [illegible]

| 42 | | | 400 |

94 *PHOENIX SYLVESTRIS. (*Palmaceæ.*) [illegible] for the '*toddy*' extracted from it. The trunks are used for temporary bridges, revetment piling, and water conduits. The wood is brown and cross-grained, and not very strong.

| 39 | 2313 | 8356 | 512 |

95 PICEA WEBBIANA (*Coniferæ.*) The *silver fir*, of the N. W. Himalaya, grows at high altitudes, 8000 to 12000 feet, in dark sombre forests, and reaches from 100 to 200 feet in height, with very short straight lateral branches. The wood is white, soft, easily split, and used as shingle for roofing, but is not generally valued as timber.

| 83 | | | |

96 PINUS EXCELSA. A handsome lofty pine growing at altitudes of 6000 to 11000 in the N. W. Himalaya, and furnishing a resinous wood, much used for flambeaux; it is durable and close-grained, much used for burning charcoal in the hills, and also for building.

97 *PINUS LONGIFOLIA. The long leaved 'Cheer' pine is the first of this genus obtained [illegible]

| | 4048 / 4668 / 3806 | | |

No.	W	E_3	f_1	p

well suited for avenues. The heart wood is black, and is termed *Iron wood* in Burmah.

78 INGA XYLOCARPA.

| 58 | 4283 | 16657 | 836 |

This valuable timber tree known as the *Iron wood* of Arracan is found throughout Southern India and Burmah, furnishing a wood of very superior quality, heavy, hard, close-grained, and durable, and of a very dark red color; it is, however, not easily worked and resists nails. It is extensively used for bridge building, posts, piles, &c., and is a good wood for sleepers, lasting (when judiciously selected, and thoroughly seasoned) for six years.

79 JUGLANS REGIA (*Juglandaceæ*).

The *Walnut* is abundant in the villages of the N. W. Himalaya, and its beautiful wood is used for all sorts of furniture and cabinet work in the bazaars of the Hill Stations.

80 *LAGERSTRŒMIA REGINÆ (*Lythraceæ*)

| 40 | 3665 | 15588 | 647 |
| 41 | | | 642 |

This is a most beautiful flowering tree from South India, Burmah and Assam, but introduced into the gardens of North India for the beauty of its luxuriant purple blossoms. In Burmah it grows to a large tree, and the wood is used more extensively than any other, except Teak, for boat, cart, and house building, and in the Madras gun carriage manufactory, for felloes, naves, framings of waggons, &c.

81 *MANGIFERA INDICA. (*Terebinthaceæ*)

| 42 | 3710 | 9518 | 632 |
| | 3120 | 7702 | 560 |

The *Mango* is generally diffused over all the warmer parts of Asia, and is much esteemed for its fruit. Its wood, however, is of inferior quality, coarse and open grained, of a deep gray color, decaying if exposed to wet, and greedily eaten by white *ants*. *It is, however, largely used, being plentiful and cheap,* for common doors and doorposts, boards and furniture, and also for firewood. It should never be used for *beams*, as it is liable to snap off short.

82 MELANORRHŒA USITATISSIMA (*Anacardiaceæ*).

| 61 | 3016 | | 514 |

The *Varnish* tree of Burmah forms large forests in conjunction with Teak and Sál, and furnishes a dark-red, hard, heavy, close and even-grained and durable (but brittle) timber, useful for helves, sheave blocks, machinery, railway sleepers, &c.

83 *MELIA AZADARACH (*Meliaceæ*)

| 30 | 2316 | 11277 | 556 |

The "Persian Lilac" of India which grows throughout China, India, Syria, &c., is ornamental when in full foliage, and covered with sweet scented lilac flowers but it is deciduous, and bare of leaves for many months, showing then only its bunches of yellow "beads", so that it is not altogether desirable as an avenue tree, though very much planted for this purpose. The soft, red colored, loose textured wood (resembling in appearance cedar) is used only for light furniture.

84 *MICHELIA CHAMPACA (*Magnoliaceæ*)

| 42 | | | |

A fine timber tree with handsome foliage and flowers. In the Dehra Dhoon it reaches 10 feet in girth. In Mysore, trees measuring 30 feet in girth, 3 feet above ground level are found, and slabs 6 feet in breadth can be obtained; as the wood takes a beautiful polish, *it makes handsome tables*; it is of a rich brown color.

85 *MILLINGTONIA HORTENSIS (*Bignoniaceæ*)

A very handsome tree for avenues; tall and straight, with graceful foliage and fragrant white flowers. It grows very rapidly, but is not long lived, and is easily injured by storms. The bark is soft and spongy, the wood is white, fine and close-grained, but of little use.

86 *MIMUSOPS ELENGI (*Sapotaceæ*)

| 61 | 2653 | 11269 | 652 |

This is an ornamental, more than [illegible] dens and avenues thr[illegible] of its foliage, and its f[illegible] close and even-grained [illegible] house and is used for cabin[illegible] building.

87 MIMUSOPS HEXANDRA.

| 70 | 2918 | 19036 | 911 |

This tree grows in South India and Guzerat, and furnishes wood very similar to the last named, used for similar purposes; and for instruments, rulers, and other articles of turnery.

88 MIMUSOPS INDICA.

| 49 | 4296 | 23824 | 815 |

This is a valuable tree of South India and Ceylon; with a coarse-grained, but strong fibrous durable wood of a reddish brown color; used for house building, and for gun stocks.

No.	W	E	f	p

89 *MORINGA PTERYGOSPERMA. (*Moringaceæ*) A handsome tall tree, with shady foliage, and of rapid growth. The wood is white and soft; and the scrapings from the root form a good substitute for the horse radish.

90 *MORUS INDICA. (*Moraceæ*) This species of *Mulberry*, as well as *Morus Multicaulis*, and *M. Nigra*, are common in Northern India: in some parts of the Punjab and Oudh being planted in connection with silk worm rearing. It is also grown in avenues, for which, however, it is unsuited, being for many months quite bare of leaves. The wood is yellow, close-grained, very tough, and well suited for turning

91 NAUCLEA CADUMBA. (*Cinchonaceæ*) A noble ornamental tree of India and Burmah, with orange colored flowers sometimes in the latter country, reaching 80 feet in height, and 12 feet in girth It has a hard, deep yellow, loose-grained wood, used for furniture In the Gwalior bazaars, it is the commonest building timber, and is much used for rafters on account of cheapness and lightness, but it is obtained there only in small scantlings.

92 *NAUCLEA CORDIFOLIA. This is also a very large tree, with a soft close even-grained wood resembling in appearence Box, but light and more easily worked, and very susceptible to alternations of temperature. It is esteemed as an ornamental wood for cabinet purposes.

42	3052 3467	10431	664 506

93 *NAUCLEA PARVIFLORA. A large fine timber tree, with a wood of fine grain easily worked, used for flooring planks, packing boxes and cabinet purposes; it is much used by the wood carvers of Saharunpore.

42			400

94 *PHŒNIX SYLVESTRIS. (*Palmaceæ*) This wild "*date palm*" is common all over India, and is valued for the '*toddy*' extracted from it The trunks are used for temporary bridges, revetment piling, and water conduits. The wood is brown and cross-grained and not very strong

39	2313	8356	512

95 PICEA WEBBIANA. (*Coniferæ*) The *silver fir*, of the N. W. Himalaya, grows at high altitudes, 8000 to 12000 feet in dark sombre forests and reaches from 100 to 200 feet in height, with very short straight lateral branches. The wood is white, soft, easily split and used as shingle for roofing, but is not generally valued as timber

68			

96 PINUS EXCELSA. A handsome lofty pine growing at altitudes of 6000 to 11000 in the N. W. Himalaya, and furnishing a resinous wood, much used for flambeaux it is durable and close-grained, much used for burning charcoal in the hills and also for building

97 *PINUS LONGIFOLIA. The long leaved 'Cheer' pine is the first of this genus obtained [illegible]

	4048 4068 3806 3672		

No.	W	E_t	f_t	p	
					... large cart
124 *TERMINALIA TOMENTOSA.					... Jodh, &c : which supplies a heavy, strong, durable and elastic wood. It is, however, a difficult timber to work up, and splits freely in exposed situations A good wood for joists, beams, tie-rods, &c., and for railway purposes, and is often sold in the market under the name of *sal*, but it is not equal to that wood.
125 THESPESIA POPULNEA. (*Malvaceæ*)	49	2201	18143	716	The *Portia* tree of Madras is much used for avenues, from its handsome appearance. It grows most rapidly from cuttings, but the trees so raised are hollow-centred; and only useful for firewood. Seedling trees furnish a pale red, strong, straight, and even-grained wood, easily worked, used for gun-stocks and furniture.
126 *TREWIA NUDIFLORA. (*Euphorbiaceæ*)					This is a large tree, from 40 to 60 feet in height, furnishing a ...
127 ULMUS INTEGRIFOLIA (*Ulmaceæ.*)					... *Ulmus Campestris*, *Erosa*, &c., growing in the N. W. Himalaya: lofty handsome trees, often planted as sacred trees by temples.
128 *ZIZYPHUS JUJUBA (*Rhamnaceæ*)	58	3381	18421	672	The *Jujube* or *Ber* is a small thorny tree found growing all over India and Burmah, and is cultivated on account of its fruit. The red dark brown wood is hard, durable, close and even-grained, and well adapted for cabinet and ornamental work. The leaves are extensively used to feed cattle in the Punjab.

VERNACULAR INDEX TO INDIAN TREES.

List of Local Synonyms of the Trees enumerated in the Preceding List.

be. *Bengali*. bu. *Burmese*. c. *Canarese*. e *English*. g. *Gurhwal*. h *Hindustani*. k. *Kunawuree*. te. *Teloogoo*. ta *Tamil*.

CHAPTER VI.

METALS.

153. The metals used in building are:—Iron lead, copper, and zinc, and some of their alloys. The purposes for which they are employed are for the making of nails, screws, bolts, straps, ties, beams, girders, pillars, pipes, gutters, and the covering of roofs. The metals just enumerated are not found to any great extent in a pure metallic condition, but are met with in combination with oxygen, forming oxides; sulphur, as sulphides; and with carbonic acid, as carbonates. The term *ore* is given to these natural compounds of the metals. Geologically speaking, these ores are generally found amongst the older rocks, the mica schists and clay slates, or even in the granite. Iron is the largest exception to this, as it is obtained also from the carboniferous formation, and sometimes in large quantities from still more recent strata.

The metallic ores occur in these natural beds or strata in detached masses, technically called *lodes or veins* These appear to have been forced into the beds when they were in a fluid state and under powerful pressure, and subsequent to the formation of the beds themselves. To reach these veins of ore, great expense is incurred in the sinking of *mines*, along with their attending *passages*, *levels*, *adits*, &c. The result of the mining operation is to bring to the surface the ore more or less mixed with earthy matter. To separate this earthy matter, the ore is *dressed.* This process consists in first picking out by the hand all the pure ore; what is rejected in the course of the picking is then subjected to stamping or crushing in mills; after which it is washed in a stream of water, the object of which is to separate the earthy matter, which being very much lighter than the ore is carried away by the stream, while the ore itself being much heavier, is hardly moved out of its place.

It should be noticed, however, that iron ores, inasmuch at they occur in beds or strata by themselves, can usually be separated sufficiently pure by the miner, and therefore but seldom need the subsequent operation of dressing.

To obtain the metal from the ore, it must undergo both the processes of *roasting* and *smelting*. The first of these operations has for its object the roasting or burning out of the sulphur or carbonic acid or water, which are combined with the metal in the ore, and the operation also renders the mass more porous, and therefore more fitted for the successful carrying on of the next process of smelting. In this last named process, the ore is mixed with an appropriate flux or reducing agent, the constituents of which having a great tendency to combine with the oxygen or silica of the ore, form compounds with these, while the metal is at the same time set free. The operation being carried on under an intense heat, the fusion of the metal takes place, and that along with the great weight of the metal itself, generally secures its thorough separation from the other foreign substances combined with it in the ore.

The metal is now subjected to *refining*, which in the main consists in a modified repetition of the smelting process, combined with certain mechanical operations.

154. Iron.—Has the most extensive application of all the metals. The chemical forms of its ores are either an oxide or carbonate. Most of the British ores contain from 25 up to 60 per cent. of the metal; if they contained much less than 25 per cent., their working would not be profitable.

155. Cast Iron.—In England the ores are generally interstratified with the coal necessary for their reduction, and in close proximity to the mountain limestone used as a flux: but in countries where the fuel and limestone are not in the vicinity of the iron ore, the manufacture of the iron cannot be carried on in a profitable manner. To obtain the metal from its ores, these are subjected to the two processes of roasting and smelting already generally described. The smelting of an iron ore is conducted in a large upright furnace, fitted to give a very high temperature, and to permit of the furnace being worked continuously. The materials employed are the ore, fuel, and flux, along with a full supply of air. Charcoal is the best fuel, and then coke: and these can be used with a "*cold blast*" of air in the smelting furnace. The choice of flux depends on the nature of the ore. For argillaceous ores, lime is required, but for calcareous ores clay is added. When coal is the fuel employed, the air is forced into the furnace in a heated state, constituting the *hot blast*.

Smelting.—The changes which ensue in the furnace are shortly these:—

The oxygen of the hot blast meeting the fuel, combines with its carbon, giving out an intense heat. The carbonic acid which results, coming in contact with the heated combustible matter above, is converted into carbonic oxide; where this takes place, the furnace is comparatively cool. The escape of a large quantity of this gas along with some hydrogen, and carbonated hydrogen, also obtained by the action of the heat on the fuel, constitutes a serious waste in the process. The iron when set free from the other matters of the ore, combines with about four or five per cent. of carbon, thus forming the fusible compound known as *Cast-Iron.* This mixture with carbon must take place, for, if it remained pure, the iron would not fuse, and thus would not separate from the slag or fused mixture of the lime used in the process along with the silica and clay of the ore.

Pig-Iron. When a sufficiency of cast-iron has accumulated in the furnace, it is tapped; the molten metal runs out, and is received in long straight gutters made in sand which have numerous side-branches. This arrangement is called the *sow* and her *pigs*, and hence the name the iron now receives of pig-iron. The iron is now in a condition quite suitable for all the purposes of casting in either light or heavy work.

156. *Quality.* The best indications of the *quality* of *cast-iron* are the color, and texture of a recent fracture. A high temperature and a large quantity of fuel produce *grey cast-iron*, of different shades of bluish-grey in color, granular in texture, softer and more easily fusible than white cast-iron: it produces therefore the finest and most accurate castings, but is comparatively deficient in hardness and strength : for large structures bearing loads in motion, it is however safer to use the grey than the more brittle white cast-iron. A low temperature and deficiency of fuel produce *white cast-iron* : which is silvery white, either *granular* or *crystalline,* excessively hard but brittle, and comparatively difficult to melt: the extreme brittleness of the *crystalline* white cast-iron renders it unfit for use in Engineering structures: *this variety* therefore is generally used for conversion into wrought-iron. The quality of a sample may be tested by striking a smart blow with a sledge hammer on its edge: if it breaks, it indicates brittleness; if it produces a slight indentation without fracture, it shows that the iron is slightly malleable, and therefore of good quality. If the fractured surface is mottled, either with patches of darker or lighter iron, or with crystalline patches, the casting will be unsafe; and it will be still more unsafe if it contains air bubbles.

Casting. The great advantage of cast-iron is the facility with which it can be run into any form. For this purpose, it is re-melted with charcoal or coke, under a blast, in a cupola furnace (*see Plate* XX.,) and run into moulds of sand or loam. It should always be allowed to cool undisturbed, for if exposed, rapid irregular cooling injures the quality of the iron and the homogeneousness of the casting. Cast-iron contracts about one per cent. in cooling. Its strength varies as its density, which depends on the temperature of the metal when drawn from the furnace, the rate and uniformity of cooling, the head of metal under which the casting is made, and its bulk. Large castings are porportionately weaker than small ones. They are more likely to be honeycombed* in the interior, and should not be depended upon to the same extent as small castings. The strength of cast-iron to resist both cross strains and crushing is increased by *repeated meltings* (up to the twelfth). For large castings a mixture should be made of certain proportions of different qualities of iron. Temperature affects cast-iron very much, great cold making it very brittle.

157. Memo. on the cost of making castings at the Canal Foundry, Roorkee. The character of the castings made at Roorkee is very various; the weight being from ¼ chittack to 50 maunds, and the moulding is in green sand, dry sand and loam; the average prime cost during one year was as follows :—

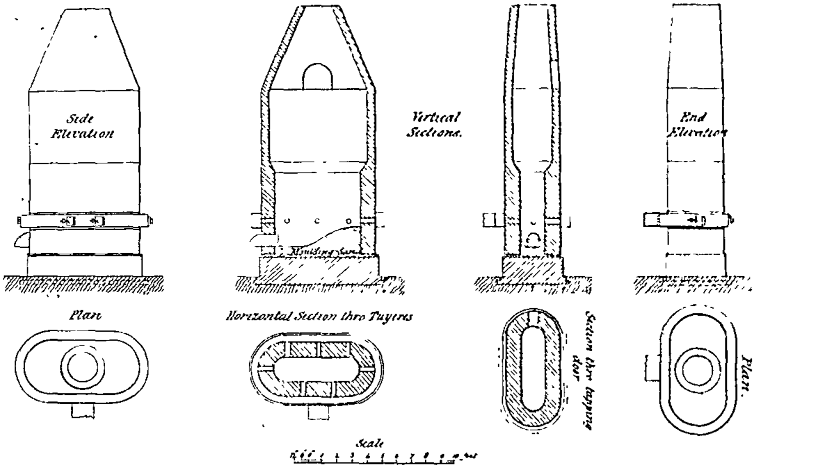
	Labor.			Materials.			Total.		
	R.	A.	P.	R.	A.	P.	R.	A.	P.
Engine and fan, ...	0	0	1·6	0	0	2·6	0	0	4·2
Boiler for do., ...	0	0	2·4	0	1	8·4	0	1	10·8
Moulding, ...	0	9	1	0	1	9	0	10	10
Melting, ...	0	0	11·5	5	3	8·3	5	4	7·3
Core making, ...	0	1	1·5	0	0	1·5	0	1	3
Dressing castings, ...	0	1	7	0	0	0·5	0	1	7·5
Repairs to Cupola, ...	0	0	2·7	0	0	5·3	0	0	8
Repairs to Foundry tools, ...	0	0	3	0	1	3	0	1	6
Repairs to patterns, ..	0	0	2·2	0	0	0·5	0	0	2·7
Total. ..	0	13	8·9	5	9	3·1	6	7	0·0

The fuel used is charcoal, and the charge is 4 maunds of charcoal to 8 maunds of iron; the iron charged is composed of No. 1 Gartsherrie pig, broken railway chairs, ordnance, Kentledge and scrap, in different proportions to suit the nature of the work.

* Small defects in the surface of castings may be filled up with the following alloy, which expands in cooling — [illegible] parts lead, [illegible] of antimony, and 1 of bismuth.

CUPOLA FURNACE,

For Melting Cast-Iron with Charcoal.



158. WROUGHT-IRON. To convert cast into *wrought* or *malleable* iron it is necessary to remove the carbon, and if possible the sulphur and phosphorus with which to a greater or smaller extent nearly all brands of cast-iron are contaminated. Oxygen is the agent used for removing the carbon; but to eliminate the sulphur and phosphorus, silicon and chemical substances (usually including chlorine, bromine, or iodine) are introduced in the furnace, and are known to the puddlers as "physic." The process hitherto most ordinarily adopted is the following:—

It is commenced by re-melting twenty-five or thirty hundred weight of pig-iron at a time in a kind of forge, called a *finery*, where the iron is partially carbonized by the action of a blast of air forced over its surface by a blowing engine. The carbon having a greater affinity for the oxygen than for the iron, combines with it and passes off as carbonic acid. Silica also separates as a slag in combination with more iron. After this, the refined pig-iron is subjected to a second fusion in the *puddling* or *reverberating* furnace, where the burning fuel is separated by a partition from the hearth (in which the metal is placed and melted) the *flame* only is conducted over the *surface* of the metal, while the *puddler* by means of a rake or *rabble* agitates the metal so as to expose the whole of the charge to the action of the oxygen passing over it from the fire; at intervals throwing in oxide of iron, salt, or other "physic" to form a fluid slag of the impurities. The oxygen of the oxide burns off the remainder of the carbon, and the silicon gets oxidised, also combining with another portion of the metallic oxide to form another slag; to separate which, the iron ("*loup*" or "*bloom*" as it is sometimes called) in the form of balls, is taken out and beaten under a heavy hammer, to be "*shingled*," that is to have the cinder forced out, and the particles of iron welded together by blows or pressure: and this is repeated several times until the iron is quite pure. During the processes of refining and puddling, the cast-iron loses twenty to forty per cent. of its weight.

The bloom after shingling is passed between rollers and rolled into a bar; the bar is cut into short lengths, which are faggotted together, re-heated and rolled again into one bar; and this process is repeated till the iron has become sufficiently compact and has acquired a fibrous structure.

Although this process of first making Cast-Iron, and then unmaking it, is the most economical and generally applicable. Wrought-Iron may be made at once from the ore by combining the processes of smelting and

puddling; and iron is so made in America, in France, and in this country: it is always a wasteful process, however, as there is much fuel as well as iron, lost.

159. From the ordinary process above described the *refining* is sometimes omitted, and the iron is purified with greater rapidity and economy by the *boiling* process, which consists of the introduction of a small quantity of steam (at about 5 lbs pressure per square inch) into the molten metal as soon as it is fuzed in the puddling furnace. The oxygen of the steam carries off the carbon, while the hydrogen unites with the sulphur, phosphorus, arsenic, &c, and moreover the steam, introduced through pipes to the bottom of the furnace, agitates the iron, and causes exposure of fresh surfaces to the oxygen passing through the furnace. After 5 or 8 minutes boiling, the operation of puddling is completed in the ordinary way with the rabble.

Bessemer Process Another process, now a good deal in use in Great Britain, *for the conversion of cast into wrought-iron, is Bessemer's process.* This method consists in injecting into the cast-iron, while still in a molten condition, a blast of air in a separate cupola, the object being to burn out the carbon and silicon from the iron; the admission of the cold air being attendent with a brisk ebullition among the molten cast-iron, due to the carbon particles being burnt by the oxygen of the blast. When the iron is run from the cupola after this process, it is found to be wonderfully

common belt, driven from shafting about 6 feet above the furnace, rotates a sheave, which is loosely jointed at one end to the puddling rabble, and at the other turns on a pin held in the hand of the puddler. The strap rotates the rabble, supports part of its weight like a suspension link, and acts as an universal joint. Its real speed, (varying from 200 to 1000 revolutions per minute) is found to give it all the mechanical energy required.

160. *Quality.* Wrought-iron may (like cast-iron) be judged of, as to quality, by the surface of a recent fracture. It should have a clear bluish-grey color, with a high silky lustre, and a fibrous appearance; when the texture is either laminated or crystalline, the metal is defective.* It is tough, malleable, and ductile. At a white heat, it becomes soft enough to take any shape under the hammer, and admits readily of being *welded*; *i. e.*, the thorough union of two pieces. In this operation, it is necessary that each surface of contact should be free from oxide (rust); to make sure of this, it is usual for the smith to shake a little sand and dust over the surfaces to be joined; the earthy matter forms a very fusible compound with any rust that may be present, and is easily expressed by the hammering.

161. The principal forms in which wrought-iron is prepared for general purposes are:—

Bar-iron.—Long pieces of rectangular section, generally square, distinguished according to dimensions of section, as 1-inch bar, 2-inch, 2½-inch, &c.

Rod-iron.—Which is in long cylindrical pieces, the different sizes of which are similarly specified, as ½-inch rod, 1¼-inch, &c.

The above forms are given by angular or semi-circular indentations on the peripheries of the rollers between which the metal is passed. The different descriptions of iron *wire* might be considered so many smaller sizes of rod-iron, but they differ from it in the method in which they are made—wire being *drawn* through circular holes in a strong metal plate, not *rolled* as rod-iron. Various forms other than the rectangular and cylindrical may be given to bars of iron by the same means, that is by having the desired form of section cut in the peripheries of the rollers; in this manner is made what is called **T** *and* **H** *iron* (in cross section resembling those letters), *Angle-iron*, like the letter **L**, also different forms of

* An exception to this is the famous Low Moor Iron, which is granular, never fibrous, and is yet very strong, and indeed is often selected by Engineers on account of its known strength, for girders, pillars, &c.

steel has of assuming an extraordinary hardness after it has undergone tempering, when it is also rendered wonderfully elastic; these two properties of hardness and elasticity adapting it for a variety of purposes for which wrought-iron would be unsuitable. Its great use is in making edge tools. These however, have often only a superficial coating of steel, which is communicated by *case hardening*. The tool is heated red hot and sprinkled over with ferro-cyanide of potassium, the carbon of which combines with the iron on the surface of the tool, making a coating of steel.

With the exception of the large and increasing use of steel for railway bars, no great branch of metallic industry can yet be pointed out as having passed from iron over to steel.

The large and economical use of steel for structural purposes, and more especially for ship and bridge building, labors under three chief difficulties which retard its progess, viz.; (*a*), a certain risk of want of uniformity in the manufactured material as delivered to the builder; (*b*), the extreme sensitiveness of steel to change its physical condition by abrupt change of temperature, brought about unavoidably or accidentally in the process of building into structure; (*c*), the physical qualities which belong to steel, necessitating special manipulation and with special tools or methods, if we are to avoid injuring more or less its valuable properties, when so built into structure.

In time however, these difficulties will probably be overcome, and steel *will be used in preference to malleable iron; admitting of economy* in mass and weight by the use of a material whose tensile strength may be taken at 50 tons per square inch.

164. Copper.—Copper is rather too expensive a metal to be used much in building. It is obtained by a somewhat complex process of smelting (or rather a series of processes) from copper pyrites, a sulphide of copper and iron. The high price of the metal enables the smelter to work ores, which do not contain over two or three per cent. of metal. Copper is sometimes found native, but only in small quantity. It is a metal of a peculiar red color; when tarnished, it characteristically becomes green, from being covered with a coating of sub-carbonate of copper. It is a very malleable and a still more tenacious metal. Sheets and wire of extreme fineness can be made of it. For building, copper is more employed in the form of its very useful alloy with zinc, *brass*.

165. Zinc or Spelter.—This metal is more extensively used in build-

ing than the last, it is much cheaper and wonderfully durable. It is obtained from either of its ores, the sulphide (zincblende)—or the carbonate (calamine) These are roasted, and then, after mixture with coke or charcoal subjected to a kind of distillation, by which the zinc, on account of its easy volatility, is separated. Though a brittle metal at ordinary temperatures it becomes malleable between 200° and 300°, and then may be rolled into sheets or drawn into wires, in which last state, however, it is hardly used at all. It is used for gutters, roofing, piping, &c., it soon becomes oxydized on the surface, but the film of oxide remains adherent, and thus protects the rest of the metal beneath from further action of the air. Whenever the air is apt to contain acid particles, as near the sea, zinc soon gives way.

166. **Lead.**—The ore of this metal is almost always the sulphide (galena). After the dressing of the ore, it is ground and divided into two quantities, one of which is roasted in a reverberatory furnace at a comparatively low temperature; by this it is changed into oxide of lead; the second quantity of ore is now added, and the heat of the furnace raised, when a re-action ensues between the oxide of lead and the new unaltered sulphide, the result of which is to produce sulphurous acid and metallic lead, the former escapes up the chimney and the latter runs from the furnace in a molten condition. It is then purified by a second fusion, after which it is quite fit for the market. For building purposes, lead is not now much employed, excepting in water fittings, such as the lining of cisterns and the making of pipes. It is singular that for these very purposes there is an important objection to lead; for it is found that if the water brought in contact with this metal be very soft or pure, it is apt to be acted upon, and even a poisonous amount of lead may thus get mixed with the water. Certain salts existing in many natural waters, prevent this action altogether; such salts are the carbonates and sulphates, and especially carbonate and sulphate of lime, and these are very common in most spring waters, in sufficiently large amount to prove a perfect protection from the evil. Waters from rivers or lakes, in countries where the primary rocks such as granite or gneiss abound, are open to be suspected of having this action on lead, and in all such cases means should be taken to ascertain by actual experiment, whether it would be safe or otherwise to pass the water through leaden pipes or store it in leaden cisterns. Recently boiled or distilled water should never be put in leaden vessels.

Sheet lead is also occasionally used as a covering for roofs (weight 7 lbs. per square foot; flattest slope 4°). When a fresh surface of lead is exposed to air or water, it becomes coated in a short time with a thin grey film of oxide, which protects the metal against further oxidation, unless there be present some acid capable of dissolving the oxide.

Lead is a very soft and heavy metal, its specific gravity is 11·44, it fuses at the temperature of 620°. On account of its contracting at the moment of its becoming a solid, it is not employed alone for casting: but when used for *type metal*, to 4 parts of lead is added 1 part of *antimony*, which prevents contraction of the alloy in cooling.

167. Tin.—The ore of this metal is called tin stone, and is a bin-oxide of the metal. The ore is treated by the process described in the beginning of this chapter. It is too expensive a metal to be used much in building, besides being too soft and too easily fused. In the form of tin plate, there is a considerable consumption of the metal; "tin plate" being formed by immersing well cleansed sheets of iron in melted tin: by which process the iron is coated with a layer of an alloy of iron and tin, which passes gradually into pure tin at its outer surface. The very slow action of air on tin gives to articles made of tin-plate, all the strength of the iron, with the brightness and cleanliness of the tin. With moderate care, in a dry atmosphere, the tin coating remains a long time, but when once a single spot is denuded, the whole surface gives way very speedily.

Tin melts at 442°. It is very malleable, and when beaten out, it forms the useful investing material, *tin-foil*.

168. Alloys.—An alloy is a compound of two or more metals. Alloys are generally more fusible and harder than the metals which enter into their composition. In making alloys, the most infusible metal should be melted first: and the quantities of the ingredients should bear definite atomic proportions to each other: otherwise the metal produced will not be a homogeneous compound: but a mixture of two or more different compounds in irregular masses, which being different in expansibility and elasticity tend to separate from each other.

Gun metal consists of nine parts copper and one of tin, with sometimes a little zinc. It is tough, strong and hard, and is used for pumps, valves, cylinders, and those parts of machinery subject to attrition.

Brass, composed of three parts zinc and five or six of copper, is used

for philosophical instruments, utensils, &c. It is ductile, tough, very tractable, taking a fine polish. Brass for locks, door handles, &c., consists of one part zinc and three of copper. Brass for turning in the lathe, should have a little lead in it besides copper and zinc; but lead renders it unfit for hammering.

Bell metal consists of seventy-eight parts copper and twenty-two of tin.

Bronze consists of copper and tin, with a little zinc and lead.

Pewter is an alloy of eight parts of tin to twenty of lead.

Soldering is the art of uniting the edges or surfaces of metals by partial fusion, or by the application of an alloy called *solder*, which is more fusible than the metals to be united. To effect this, the solder must be of such metals as will, when fused, combine readily and firmly with the pieces of metal to be united—with *each* of them, when they are of different kinds. Thus different metals require different solders to unite them. Solder for tin is made of one part tin and two parts lead—that for iron, copper and brass, is an alloy of three parts zinc to four of copper; lead alone, or an alloy of lead and tin is used as a solder for lead, &c. The application of the fused solder forms an alloy at the surfaces in contact, and that this may take place more effectually, some other substance is employed as a *flux* along with the solder, being applied to the smoothed and cleaned surfaces of the metals before soldering. For this purpose borax is generally used with brass; sal-ammoniac or resin with tin, copper and iron: spirit of salt (hydrochloric acid) with zinc. What is called *Fine Solder* consists of two parts tin to one of lead. This is what is used by pewterers and for tinning copper vessels, &c. *Hard* solder is one which requires the metals that are to be united previously brought to a red heat, or even almost to the point of fusion. *Soft* solder is such as may be applied without raising the metals to so high a temperature, such as solder formed of lead and tin, in which lead is in excess. When sheet metals are nailed, the nail holes should be covered with a small patch of solder, which is called "dotting."

169. Indian Metals.—*Iron* is found in many parts of India, in the Salem and Beypore districts of the Madras Presidency, in the Vhyndhia Hills near Jubbulpore, and the Nerbudda territory, in Jhansie and Gwalior, also in Assam and Burmah, and various other parts. *Copper* is found in Kumaon, Rajpootana, &c. *Tin* in Burmah and Malacca. The following extracts are from the Indian Catalogue of the International Exhibition of 1862, and from Memoirs of the Indian Geological Survey.

IRON.—*Beypore.*—The bulk of these ores are rich magnetic oxides, and when freed from earthy matter, and ready for the blast furnace, contain about 72 per cent. of iron. They are found in mountain passes, and are obtained by quarrying with a crowbar. The quantity is so large, that it is not necessary to have recourse to underground operations. They are quite free from sulphur, arsenic, and phosphorus, and upon a large average have been found to yield 68 per cent. of metal in the blast furnace.

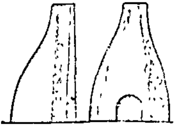
170. *Salem.*—The iron of the Salem districts of the Madras Presidency is a rich magnetic oxide of iron, very heavy and massive. The yield averages 60 per cent. of metallic iron. The ore is, however, often mixed with quartz, which is a very refractory material in the blast furnace Limestone, and, in some places, shell lime, is employed as a flux, and the charcoal of some kind of acacia is the fuel.

The method of smelting is here, as in other places, very simple, and the apparatus used very cheap. The iron produced is of excellent quality, but the quantity is but small.

The shape and construction of the furnaces vary slightly, but that most generally used is nearly cylindrical, tapering into an irregular cone at the top. The furnaces are constructed entirely of red-clay mixed with sand; they constantly require to have the inside renewed by fresh linings of clay, which cannot stand more than three or four day's working The height of the furnace varies from 3 to 5 feet, with a diameter of the interior of from 9 inches to 1 foot. The furnace itself at the ground is about 2 feet wide, and tapers sometimes from the ground, sometimes from about ⅓rd or ¼th of the height; the walls are from 4 to 6 inches thick. The front of the furnaces is for the most part nearly vertical, the back therefore slopes considerably more than do the sides, as shown in the annexed figure, giving a section of an iron furnace at Chaindanumgalum, in the Namkul Talûq. In some cases, however, the furnace is a regular cone.

Inside the furnace, the ground is generally excavated to the depth of about 1 foot, to form a hearth for the bloom. A semi-circular opening from 1 foot to 14 inches high is either left in the front wall, or is subsequently cut into it while the clay is still moist. This is filled up with clay before the commencement of each smelting.

Native Iron Furnace.



The blast required for the smelting is obtained by using two bellows, each made of a sheep or goat's skin, and worked by hand in the ordinary way by a man squatting in front of the furnace. The nozzles of the bellows are made either of thin sheet iron, or tin plate, or sometimes of bamboos, and these are inserted into a clay tuyere entering at the bottom of the front opening, and carefully luted. The tuyeres reach to the centre of the furnace. The bottom of the furnace is covered with a layer of charcoal dust, to prevent the adhesion of the bloom. By using the bellows alternately, a tolerably continuous blast is produced.

The furnace is first filled to the top, or very nearly so, with charcoal, which is ignited by means of a burning ember passed through the tuyere. As soon as flames issue from above, a small charge of the powdered iron ore, well moistened to make it cake together, is introduced through the apex and covered with charcoal: this is

followed by successive charges of ore and fuel, until the proper quantity of ore is in the furnace. The blast is now strongly applied, and continued from two and a half to four hours, according to the size of the furnace. The process is then considered complete, the semi-circular aperture in front of the furnace is opened, and the bloom is removed. A number of heavy blows with a hammer or mallet are given, to knock off as much as possible of the adhering oxide, and the bloom is then cut half through with a hatchet, and allowed to cool. The object of cutting open the bloom in this way is to exhibit the grain to the purchaser.

Charcoal is the only fuel used, but different values are attached to different woods for the purpose of charcoal, and frequently two or three different kinds are used at different levels in the furnace. What the effect of this may be cannot be clearly stated. No flux is used.

The ordinary charge for one of these furnaces is about 18 lbs. of ore, and the smelting occupies two to three hours. The average out-turn is three blooms in the 12 hours, four men being required to work the furnace; but the furnaces are never worked continuously. In some parts, larger furnaces are used, and the charge for each smelting amounts to 35 lbs of ore.

The process of refining the metal thus obtained consists merely in heating the bloom several times, and subjecting it to a good hammering, by which the slag is in great measure got rid of. It is then hammered into rude bars about 1 foot in length and about 2 inches in width. From these bars the "Wootz" or Indian steel is prepared.

171. *Cuttack.*—An abundance of this ironstone is found in the district of Sumbulpore, and it is plentiful in the Cuttack Tributary States of Talchere, Dhenkanal, Pal Labara, and Ungool, and indeed throughout the hilly country bordering the settled districts of this province on the north-west. The whole of the iron used for various purposes in this division is supplied from these local sources. In Sumbulpore, the crude iron is sold at one anna per seer, which is equivalent to about three-fourths of a penny per English pound. No flux is used; the broken ironstone is mixed with charcoal, which can be prepared in any required quantity on the spot, and the mixture is then, probably in alternate layers, put into the furnace,—a kiln in minature standing about 4 feet high, and made of clay. The top is open, and the bottom and sides thoroughly closed. The fire is maintained by an artificial blast, introduced through a fire-clay pipe which is sealed up with clay after the insertion of the nozzle of the bellows. The slag escapes, or more properly is raked out, through an aperture made in the ground, and which runs up into the centre of the furnace base. Three men—one to serve the fire, and two to work the bellows—are required to tend each furnace. The charcoal used is made from the Sál or *Shorea robusta*. Limestone in calcareous nodules is abundant on the spot, but is nowhere used in smelting.

172. *Shahabad.*—Abundant quarries of the peroxide and proto-peroxide of iron, as also of iron-pyrites, abound in the most accessible portions of the Kymore range The Kymore range is the north-easterly spur of the Vhyndhia range, and fills all Southern Mirzapore and Shahabad. Most of the ores are peculiarly rich in metal, some of them even yielding 70 to 75 per cent of pig-iron, but without accessible coal they are comparatively useless. Considerable quantities of iron, and that some of the best in India, are annually produced in Palomow, Rewah, Bidjugghur, and Singrowlie. The iron from the latter place, in particular, bears a high character in the market, being tough, flexible, and easily worked, while English iron, having originally been smelted

from an inferior ore (the clay ironstone) and with mineral coal, is almost unworkable by native blacksmiths.

The ores are extremely rich, and the cost merely nominal, probably not more than 2 per cent. upon the cost of quarrying; and the ores being all above ground, would reduce the cost of quarrying to a minimum. Charcoal, as used by native smelters may be obtained at 10 or 11 maunds per rupee, say Rs. 2½ to 3 per ton, in the forest, to which, of course, must be added cost of carriage to site.

173. *Jubbulpore.*—The Azureea mines are situated on a hill consisting of iron ore, found at 1½ feet from the surface, and extending over an area of about 60,000 yards square and 30 feet deep. The ore exists in thin *flakes* of a grey iron color and metallic lustre The nature of fuel used is common wood charcoal, and for refining the metal, bamboo charcoal; the fuel is brought from a distance of about 5 miles from the mines. The ore and charcoal are thrown, in small quantities, every half hour into an earthen furnace five feet high and two feet square; a part of the bottom of the furnace is filled with fuel only, this being kindled, a pair of bellows is applied to raise the heat, and a passage made at the side of the furnace for the melted metal to run out Four maunds (320 lbs) of ore and 2½ maunds of charcoal are daily used in a furnace, the fuel is used in the proportion of 5-8ths or 62 per cent. of the ore for smelting, and 1-5th more for refining the metal. A furnace furnishes daily 2 maunds (160 lbs.) or 50 per cent. of the crude iron from 4 maunds of the ore; this when forged, yields 30 seers, or nearly 19 per cent of wrought-iron. The ore is simply dug out with pickaxes; it costs 6 pie per maund for excavating and carrying to the furnace. The fuel or charcoal costs Rs. 1-1-6 per maund of wrought-iron. The entire cost of the pure metal obtained amounts to Rs. 1-13 per maund, including labor and materials. The ore is generally sold at the works and conveyed on bullocks to different markets. When brought to Jubbulpore, the nearest market, it costs 2 annas 8 pie per maund, exclusive of duty.

174. *Punjab.*—The iron ores of the Punjab are produced along its north-eastern mountain frontier as well as in the lower hills of the Sulaimaní and Wazíri ranges, and those to the south-east of the Bunnoo district, and to some extent in the Salt range. On the other side of the province, in the hilly portions of Gurgaon district, iron is found, and although the hills in the Delhi district exhibit no specimens of iron ore as such, there is in them a ferruginous rock, and the Mahrúli hill, which yields iron ore, is one of that group of outliers that forms a continuation as it were of the Aravalli range, and properly within the Delhi district.

Along the Himalayan frontier, the principal places of production are the Hill States of the Simla district (Júbal, Dhámi, Bishahr and Rámpúr). Again at Suket and Mandi, iron is largely produced, and the mines at Kot Khai, Fatihpúr, and Bhir Bangál of Kangra are famous. Pursuing the line of Hill States, the iron of the Chamba hills next demands notice, and the next division up to the Hazara district is included in the territories of H. H. the Maháraján of Kashmír. In these territories, the best iron is found at Reyási in Jummú, while the iron found at Soóf and Kutyar in Kashmir proper, is not so good. Iron of good quality, but inferior to that of Reyási, occurs in Bunch, the territory of Raja Motí Singh, feudatory of Kashmír. Reverting once more to British territory, we find iron ore at Bakot in the Hazara district. Next to this, in the hills due north of Peshawur, is the source of the Bajaur iron, which is of fine quality, and is used in the manufacture of the gun barrels of Kohat

and Jammú; and not a little also, it may be presumed, in the formation of steel for the blades of Bukhára and Peshawur.

Nowhere within British territory is indigenous steel procurable, at all events such steel as would be of any use in the finer classes of manufacture; the cutlery of Nizámábád and Guzrát is exclusively manufactured with imported steel, while the inferior kinds are not steel at all but merely polished iron.

The iron ores of the Himalayan districts are mostly magnetic oxides of singular purity, and exist in a great measure in the form of an iron sand or aggregate of particles of oxide of iron. These are no doubt produced in the detrition or disintegration of schistose and micaceous rock containing particles of metal; this kind of rock or ore is called "pathar dhoó."

In other places the ore is found as a massive hæmatite, and is sometimes associated with copper. In Suket, and a few other localities, a glistening micaceous iron ore or glistening hæmatite occurs, but the natives often call it "antimony of Ispahán" (surma Isfaháni). In one or two instances it is exhibited as a hydrated peroxide.

Iron exists at Kanigorum in the Wazírí hills; it is found also as a hæmatite in several parts of the Salt range, and in the Chichalli range, on the other side of the river. In a few places near the same ranges, and especially associated with shale, this metal is found in the form of a sulphuret, *i. e.*, iron pyrites, and the beds of the "kasis" and "kahi" (earth containing anhydrous proto-sulphate of iron) are said to result from the decomposition and oxydization of these pyrites. Hydrated peroxide in the form of ochre, is procured in a number of places in the Punjab, and forms the coloring matter in the "gil-i-zard," or yellow earth, and in the "Múltáni mitti" used by the dyers.

175. The following account has been received from the Deputy Commissioner of Gurgaon: "The hill from which the iron is obtained in Firozpúr is known generally by the name "Jharkah," and the iron mines in it are called "búrá" mines, in which by digging to a depth of 6 feet, pieces of a red and slightly glistening hæmatite are obtained, called "búrá." From this ore iron is obtained. In digging for the ore, the miners first come upon a quantity of red earth and soft stone discolored by iron, which is used to make roads with; below this the hæmatite is found. The ore is first pounded with stones into small fragments, and then taken to the smelting furnace, which is called "nándri." This furnace is of a round conical shape, narrow at the top and wide at the base, and about 9 feet high; into it is put 13 maunds of the ore (this quantity of ore is called a "gan") and 12 maunds of charcoal,—some of it above, and some below, the crushed ore. Each furnace is fitted with two pairs of bellows, which are worked to supply a blast of air to the fire during eighteen hours continuously;—the melted iron falls to the bottom. Thirteen maunds (= 1 gan) of ore yield 3 maunds of metallic iron,—this is taken out and repeatedly heated and hammered till it becomes pure, when about 1½ maunds of the unmixed metal remain. In thus bringing the iron to its pure state ("called a pakka"), 5 maunds of charcoal are required besides the 12 consumed in the smelting furnace. Thus to completely work 13 maunds of ore, 17 maunds of charcoal are required, at a cost of Rs 8-8, (at 2 maunds per rupee,) the total cost of the process is Rs. 10-10, thus —

	R.	A.	P.
Charcoal, 17 maunds, ...	8	8	0
Wages of workmen at the smelting furnace, ...	0	10	0

	R. A. P.
Wages of workmen at the bellows and those who hammer out the iron, ...	0 12 0
Wages of workmen who work the metallic iron by repeatedly heating it, &c., ...	0 12 0
Total Rs., ...	10 10 0

176. The following are the kinds of iron to be met with in the Lahore bazars:— 2nd class steel, "asbát," used for coarse cheap cutlery purposes.

Iron, variety "khéri," used for agricultural and other implements.

Iron, variety "barki."

Iron, variety "guleri," comes from Gwalior in Hindoostan; it is a tenacious metal and used for wire drawing, gun barrels, &c.

Besides these varieties, the following kinds are met with in the shops of the "lohtis," or iron sellers, who are the persons who buy wholesale from the Naurias and other merchants and then sell by retail to the blacksmiths, or "lohars." Of Indian iron, the varieties are—the "kheri," noted above, this is said to be brought from Hindoostan, it is an iron of unpromising appearance, but exhibits on being forged its superior quality; it is much employed for carpenters' tools, adzes, &c., and occasionally for swords. It values about 4 seers per rupee; its probable origin is the Jaipür territory.

"Faulád" or steel, used to be imported from Hindoostan for the manufacture of armour, shields, &c.; at the present day when the manufacture of such armour is not carried on, the import has ceased, the steel used to be brought in "chaktis" or circular disks, about ⅝ of an inch thick. "Guléri" iron, which is sold in pigs, and values Rs. 6-12 per maund, is a tenacious iron used also in wire drawing. The imported Indian irons are brought up by Naurias to Hatras between Allygurh "and Agra, and from thence taken to Amritsar, which is the Punjab Mart." Of Punjab iron, the "bajauri," from Bajaur, north of Peshawur, is not much exported to the Central Plain districts, though it was formerly for the purposes of gun making. Bajauri iron is still largely used at Kohat in the remarkable process of their gun barrel making, and is used also at Kálabagh and other places. The guns and cutlery made at Nizámábád, in the Gujranwala district, are of "guléri" iron or of "asbat." European steel is also employed for cutlery

Barki iron is brought down from Suket and the Mandi mines, it values Rs. 6-12 to 7 a maund, and finds its way on backs of mules and donkeys to Dinanagar whence it comes to Amritsar; it is probable that other irons of the Kangra district mines are similarly imported under this name Attempts have been made by individual traders gát... down the iron of the Chamba territory, but the cost of carriage is too great to hills next ... seldom imported.
in the territories of H. H. th... are European, and brought from Bombay; the varieties iron is found at Reyási in J...
...mir proper, is not so good ... ...on sold in long flat bars; it is used for making tires of ... Rásch ... 6-12 a maund.
... pieces of iron, value Rs. 7 a maund; and also "gol kandla," a ...rs. Value Rs 8 a maund.

"Chadar," or sheet iron, value at Rs. 8 a maund, is employed in making "taras" large iron cauldrons, &c.

"Chakor sink" and "chakor kandla,"—are varieties of iron, imported in long rods, 15 feet or so, about 3 inches broad and ¼-inch thick,—this sells at Rs. 9 a maund. When the rods are thin, it is called "chakor kandla," and fetches Rs. 7 per maund.

These bars are stamped with a European trademark when of the first quality; these are the most approved, and are called "sacha chakor," (genuine, "chakor,") and fetch Rs. 9-8. If these bars are only the same in shape without the stamp, they fetch Rs. 9 and Rs. 7, as above-mentioned.

Another variety is "asbât," a hard but brittle kind of steel, selling at 3½ seers per rupee; it is imported in bars, and is used for tools on account of its hardness.

A kind of iron is sold in the bazars called "fâlli," being sold in pieces of a fusiform shape, tapering at each end. This is probably a hill iron.

Raniyunge.—Iron is also found in considerable quantities in the Raniguuge district, near the famous coal fields, but the amount of sulphur present in this coal, prevents its being satisfactorily used for smelting the iron.

177. COPPER—The fuel used for smelting, is charcoal made from the extensive forests in the immediate vicinity of the mines and works in Landoo, in Dalbhoom, and Singbhoom, in the south-west frontier of Bengal, about 140 miles from Calcutta.

Copper is found in the Goorgaon and Hissar districts, also in Kangra, the Salt range and Kashmir. In Hissar the ore is obtained by mining the hill side; the work is carried on only by day, and then with the aid of lamp light. Occasionally a rush of water causes the work to be stopped, and as there is no mechanical contrivance for controlling the flood, not unfrequently the particular spot has to be abandoned altogether. The ore obtained from the mine is broken into pieces and smelted sufficiently to make it cake; on this, wood and the common "upla" (dry cow-dung) of the country are heaped, and the mass set on fire. The process of extracting the metal is similar to that of burning lime; the copper, contained in the pulverized and caked mass, percolates through the calcined refuse, and finally forms irregular shaped fragments at the base.

178. TIN.—*Malacca*—Charcoal made from the Gomposs tree, is the only description of fuel employed. A funnel-shaped blast furnace, 6 feet high and 4 feet diameter at the mouth is used. The sides of the trunk and funnel-hole are shaped and backed with clay. The fused matters escape from the cavity and flow continually into an exterior reservoir, hollowed out for that purpose, from which the liquid metal is ladled out into moulds, shaped in moist sand. The trunk is filled with charcoal, and combustion is accelerated by a cylindrical blowing machine, worked by eight men. When the whole mass is brought to a red heat, the crude ore is sprinkled on top of the burning embers and kept constantly fed, by successive charges of charcoal and mineral Each charge consists of 30 piculs of washed ore, containing from 45 to 60 per cent. of tin.

Antimony and Lead are found in several districts of the Punjab, but apparently are not much worked.

CHAPTER VII.

PAINTS, VARNISHES, &c.

179. Paints.—Paints are mixtures of certain fixed and volatile oils, chiefly those of linseed and turpentine, with certain metallic salts and oxides, and other substances used either as pigments or *stainers*, or to give a body to the paint, and to improve its drying properties.

The principal materials used in painting are—*White and Red Lead, Red and Yellow Ochre, Prussian Blue, Verdigris* (for green color), *Lamp Black, Litharge, Linseed Oil, and Turpentine.* The charcoal of babool and some other woods, very finely ground, is also used to make a black paint. Other colors, besides those directly obtained from each of the above-named substances used alone, are made by their combination: white lead is used with all when it is desired to lighten the color; thus a lead color is obtained by mixing a little lamp black with it.

Indigo and yellow ochre are sometimes mixed for green paint, as also chalk and copperas; but paint made with them, though answering tolerably well for interior work, falls in powder when exposed. Mineral paints are the most durable.

180. *Litharge* is a preparation of lead, obtained from the film formed on the surface of the metal when in a state of fusion. This film exposed to heat in open vessels produces a yellow substance, used as a paint, and called *massicot* (protoxide of lead); and this partially fused with charcoal, is the common but impure litharge. The *massicot* carefully heated without fusion, changes its color and becomes *red lead* or *minium* (deutoxyde). *White lead* (carbonate) is made from the crust formed on the surface of cast lead, when exposed to the vapour of acetic acid or vinegar. *Red* and *yellow ochres* are colored earths. *Prussian blue* is a chemical combination of iron with the compound named *cyanogen* (which means *producing blue*): it is prepared by a long process which it is needless to give here. *Verdigris* is produced by the action of vegetable acids on copper. *Lamp black* is soot collected from the burning of resinous and oleaginous matters.

Linseed oil, having the property of drying, is the oil always used. It is generally boiled with the addition of a small quantity of litharge and sugar of lead, and it more particularly, when thus prepared, goes by the name of *drying oil*. Native painters use a preparation of linseed oil with *sandarach*; this resin (called *sundroos* or *soondrus*, also *Luhrooba*) being first melted over a strong fire, and the oil then added till the whole is of a semi-fluid consistency admitting of being drawn out in threads. In this state it is kept, and with further additions of oil, as required, is both employed as a varnish and mixed with colors for painting.

Turpentine is not generally used for external or finishing coats, as it does not stand exposure so well as oil: it is, however, so used with white paint, which it discolors less than oil does. When the finishing coat is laid on with turpentine only, the work is said to be *flatted*. The turpentine employed in painting is distilled with common water, by which it is freed from resinous matters, and is called *oil*, or *essence*, or *spirits of turpentine*, being known in commerce as *turps*.

White zinc, or oxide of zinc, is in use as a substitute for white lead. It is stated in Hunt's Hand-Book that this zinc-white, "although of a beautifully white color, is unfortunately to a certain degree, transparent; and it is stated by painters, that it does not possess the covering properties or the body, of the carbonate of lead. Another difficulty attending the use of zinc paint, arises from the circumstance that it remains on the wood a long time before becoming sufficiently hardened to admit of a second coat being laid on; whilst as most of the compounds sold under the name of *patent dryers* contain lead, the introduction of this substance gives it the property of becoming black when exposed to sulphuretted hydrogen, and thus entirely destroys one of its most valuable characteristics. This arises from the fact, that the oxide of zinc will not combine with oil to form a plaster, in the way in which the oxide of lead does. It is much to be wished that the resources of modern chemistry may be at length found equal to the removal of this disadvantage; as from the baneful influence exerted by white lead, both on the persons who are employed in its manufacture, and on the painters by whom it is applied, it is greatly to be desired that some good and equally cheap substitute for this substance may be discovered."

181. The first thing to be done in painter's work is the cleaning and smoothing of the surface to be painted. Before painting on resinous woods,

it is further necessary to provide against the defacement of the work by the exudation of resin from the knots. To effect this, red lead mixed with *size* is generally applied, and the surface is afterwards smoothed with sand paper or pumice stone. This is technically called *killing* the knots. For fine work, knots may be cut out to the depth of one-fourth of an inch, and pieces of the same wood inserted, simply glued in, and not compressed; for if so, they might afterwards swell and spoil the surface. Holes and indentations on the surface are filled up with putty, made of whiting and linseed oil. This is done after the application of the first coat of paint. Heads of nails should be punched in, and stopped, with putty. The first preparatory coat of paint, which is most frequently of white lead well diluted with linseed oil, is called *priming.* The work should be well rubbed down between each coat, to bring it to an even surface, with pumice-stone or sand paper. Should the knots be apparent through the second coat they must be covered with silver leaf.

In repainting old wood-work, it should first be scoured with soap and water, and if smoky or greasy, lime-washed; when dry rub down as above. Any parts of the paint that are chipped off or blistered must be gradually brought up by touching them 3 or 4 times with color, then re-paint. When much blistered, it is necessary to get rid of the old paint, which may be quickly done by applying a charcoal fire-holder or brasier near to it.

Instead of paint, wood-oil *(gurjun-tel)* is sometime used. It is a liquid resin, and should be prepared for use by boiling with a little dammer, which gives it a polish and causes it to dry quicker, but the dammer should not be added when it is to be exposed.

Wood-work should be quite dry, as also stucco, before painting. In terraced-roofs this must be carefully looked to.

The painter is generally provided with one or more assistants, to grind and prepare his colors, &c. One man can grind about 15 chittacks of red ochre, 11 of white lead, or 5 of verdigris, per diem.

In laying on the color, the brush should be applied at right angles to the face of the work, the ends of the hairs only touching it. The paint is thus forced into the pores of the wood, and equally distributed; whereas, if the brush be applied obliquely, the paint will be left in thick masses where it is first applied. In India, paint brushes are made from the sinews *(tant)* of cattle, and lime-wash brushes from *moonj* or hemp.

EXAMPLES OF PAINTER'S WORK.

	2 Coats—100 Superficial Feet.						Priming, 100 superficial feet.	Proportions for Paints.									
	White.		Green.		Red.			White.	Black.	Lead.	Flesh.	French Grey.	Green.	Chocolate.	Straw.	Stone.	Killing Knots.
								Parts.									
White Lead ...	2 srs.	2 srs.	1 sr.	1¾ srs	..	...	3 chs.	80	...	56 lbs.	56 lbs	56 lbs	5 lb.	...	56 lbs	56 lbs.	...
Linseed Oil ...	1 „	1½ „	1 „	1½ „	1 sr.	1½ ssr.	5 „	18	73	3 gals.	3 gals.	3 gals.	½ gal.	3 gals	3½ gls.	3½ gls.	...
Prussian Blue	½ ch.	...	...	...	...	..	... ...	..	1	...	...	¼ lb.	½ lb.	...	...	...	...
Turpentine ...	½ „	...	½ ch.	...	...	...	... ...	4	...	1 pt.	1 pt.	2 gals.	1½ gls.	1½ gls.	1½ gls.	½ gal.	...
Verdigris ...	...	...	10 „	4 ch.	...	...	... ...	...	...	...	...	...	15 lbs	...	...	...	..
Red Ochre ...	...	...	...	...	1 sr.	2 srs.	... ...	..	...	...	1 lb	...	...	...	10 lbs.	...	...
Red Lead ...	...	...	...	...	1 „	...	... ...	...	...	...		...	...	...	...	...	15 lbs.
Chalk	...	...	...	...	...	...	12 chs.	...	...	...	...	...	...	...	...	...	...
Lamp Black ...	...	...	...	...	...	...	... ...	...	28	1 lb.	...	...	...	2 lbs.	...	...	½ lb.
Spanish Brown	...	...	...	...	...	...	... ...	...	...	...	...	...	...	56 lbs.	...	...	...
Litharge ...	...	..	...	..	...	...	... ...	...	1	...	...	...	...	...	...	...	...
Burnt Umber	...	...	...	...	...	...	... ...	...	...	...	...	...	...	..	...	½ lb.	...
Glue	...	...	...	...	...	...	... ...	...	...	...	...	...	...	...	...	...	8 lbs.
Whiting ...	...	...	...	...	..	...	... ...	...	...	...	...	...	...	...	...	...	½ lb.
Painters ...	1	1	1	1	1	1	1										
Bildars, ...	3	3	4	5	2	2	1										

182. Distemper.—The coloring of plastered and whitewashed walls may be, and commonly is in this country, laid on with water or with water and size, instead of oil; a kind of painting known by the name *distemper*. The materials chiefly employed for this purpose are *red* and *yellow ochre*, the flowers of the *dhâk* tree, the red earth called *hirmzee*, *orpiment*, *indigo*, and *blue vitriol* (neila tutya).

The *dhâk flowers* give a pink, light orange, or buff color not very durable. *Orpiment* (hurtal) is a yellow colored mineral, a compound of sulphur and arsenic found in a crystalline form in various rocks. There is also an artificial orpiment, and from both the natural and the artificial is made the color commonly knownby the name of *king's yellow*. *Blue vitriol* is a sulphate of copper, or combination of copper and sulphuric acid, generally prepared artificially, but sometimes obtained also in a fluid state in copper mines.

Combinations of the above coloring materials are employed to produce drab, stone color, &c., &c., and the depth of color is reduced at pleasure by the addition of whitewash. This kind of coloring work is in India generally performed by the masons, and if carefully done, with plenty of sizing, looks very well.

183. The following description refers to this kind of work as executed in Calcutta, and a few recipes are given of some of the most favourite colors :—

When the walls are rough, and not lime plastered, they are to be enamelled with lime plaster, so as to make the surface smooth. Then thick curd or *chânâ* (छाना), [illegible] mixed with lime water, or simply milk and water of equal proportions, is to be washed over the surface, to form a body for the water coloring.

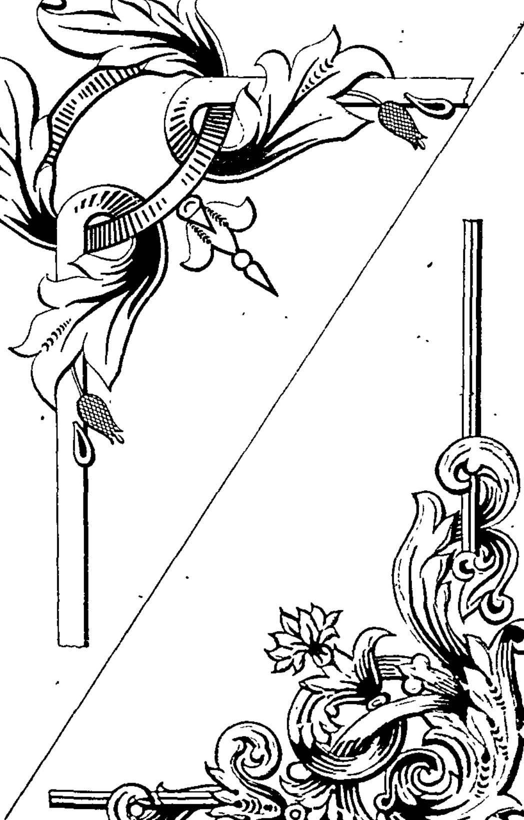
The water color to be mixed with half milk and half water, with white of eggs, and pure China glue, the latter previously boiled in water and made into liquid The color so prepared, to be laid carefully on the walls, in one coat, with an English brush, so that no cut shades be visible on the walls.

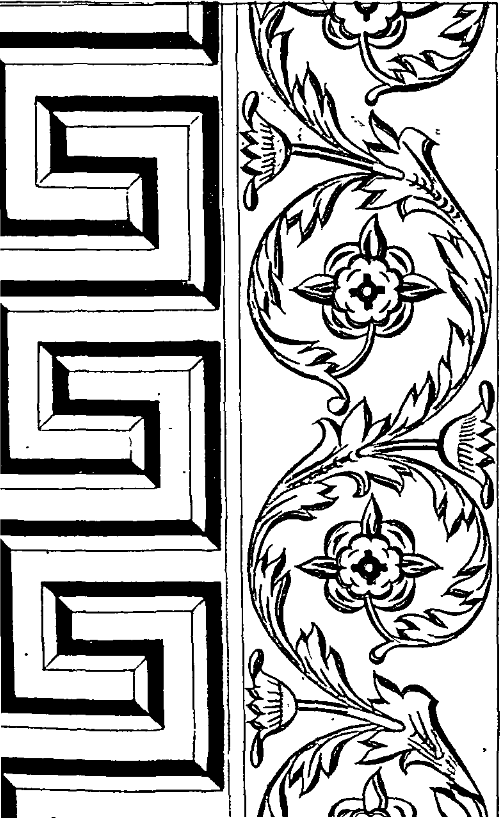
Labor for coloring, about 2 annas 6 pie per 100 superficial feet.

Ditto for flowers in the corners, &c, according to size and description, from 1 anna 6 pie to 3 annas each.

Ditto for border or lining with different colors, according to size and description, from Rs. 1-4 to 1-12 per running foot.

184. Varnish.—Is a solution of various resinous substances in rapidly drying solvents.





Statement showing rates and ingredients for different descriptions of water coloring, borders, flowering, &c., for 100 superficial feet of wall surface.

		S.	C.	RS. A. P.	RS. A. P.
STONE COLOR.	Whiting powder, ...	1	0	0 2 0	
	Umber, burnt, ...	0	½	0 0 7½	
	Chrome yellow, ...	0	2	0 4 0	
	Glue, ...	0	2	0 2 0	
	Vermillion, China, ½ tolah, ...			0 1 8	0 9 10½
CANARY.	Whiting powder, ...	1	0	0 2 0	
	Glue,..	0	2	0 2 0	
	Chrome yellow, ...	0	2	0 4 0	0 8 0
BUFF.	Whiting powder, ...	1	0	0 2 0	
	Glue, ...	0	2	0 2 0	
	Chrome yellow, ...	0	2	0 4 0	
	Yellow ochre, ...	0	1	0 0 1	0 8 1
GREEN.	Whiting powder, ...	1	0	0 2 0	
	French green powder, ...	0	4	0 10 0	
	Glue, ...	0	2	0 2 0	0 14 0
BROWN.	Whiting powder, ...	1	0	0 2 0	
	Glue, ...	0	2	0 2 0	
	Burnt umber, ...	0	2	0 3 9	
	Meena, ...	0	3	7 8 0	7 15 9
BLUE.	Whiting powder, ...	1	0	0 2 0	
	Glue, ...	0	2	0 2 0	
	Prussian blue, ...	0	2	0 3 0	0 7 0
PURPLE.	Whiting powder, ...	1	0	0 2 0	
	Glue, ...	0	2	0 2 0	
	Meena, ...	0	2	5 0 0	
	Prussian blue, ...	0	2	0 3 0	5 7 0
PINK.	Whiting powder, ...	1	0	0 2 0	
	Glue, ...	0	2	0 2 0	
	Meena, ...	0	2	5 0 0	
	Vermilion, China, ...	0	2	1 9 0	6 13 0
FINE WHITE-WASHING, 2 COATS.	Water lime,..	1	0	0 0 6	
	Shell lime, ...	½	0	0 0 9	
	Stone lime, ½ cubic inch, ...			0 0 6	
	Eggs, curd, sugar, pots, scaffolding, &c.,			0 1 9	
	Labor, ...			0 4 8	0 8 0

It is applied to ornamental woods and to painted surfaces, to protect them against injury from moistures, &c., and to impart a clear shining appearance. On a surface to which it has been applied, it is a thin coat of hard and transparent resinous matter, and the varnish prepared for use is this resinous matter in solution. It is dissolved in alcohol (spirits of wine), drying oil, or turpentine, which dry up after the varnish is spread thin over an extended surface.

The following compositions make approved varnishes:—

Sandarach, ...	250 parts.	Animé resin,..	2 lbs.
Mastic, ...	64 "	Litharge, ...	1 oz.
Elemi resin, ...	32 "	Sugar of lead, ...	1 "
Turpentine, ...	64 "	Turpentine, ...	5½ qts.
Alcohol, ...	1000 "	Linseed oil, ...	3 "
Copal, ...	300 "	Pale shell lac, ...	750 "
Oil of turpentine, ..	500 "	Mastic, ...	64 "
Linseed oil, ...	200 "	Spirits of wine, ...	1000 "

These are carefully boiled and strained. The linseed oil used for this purpose is prepared as a drying oil.

Sandarach, mastic, elemi, animé, copal and *lac*, are substances produced by different trees: the first obtained from Africa; the second from the Grecian islands; the third from the West Indies; the fourth from South America; the fifth from both East and West Indies; and the sixth from the Eastern Islands and many parts of Hindoostan.

A kind of varnish called *Dhoona* has been obtained from the *sál* tree.

Lac is obtained from several common trees, peepul, dhak, &c. It exudes from the punctures made by a little insect known as the lac insect. The lac as thus first produced on the branches of the trees, is called *stick lac*; the same, pounded and cleansed, goes by the name of *seed lac;* and this again, melted, strained, and dropped on smooth plantain leaves, forms the thin sheet of purified resin known as *shell lac*. The dried dead bodies of the insect are used to form the well knows scarlet dye, *(Lac* or *Lake,)* while the prepared resinous exudation is utilized as an ingredient in varnish and in *lacquer*, which is the name particularly applied to varnish made of lac, with the addition of various coloring matters, and employed principally for metals.

Brass Lacquer.		Gold Lacquer.	
Pale shell lac, ...	1 lb	Pale shell lac.	¾ lb.
Gamboge, ...	1 oz.	Sandarach, ...	3½ lbs.
Cape aloes,..	3 ,,	Turmeric, ...	1 lb.
Alcohol, ...	2 galls.	Gamboge, ...	2½ ozs.
		Alcohol, ...	2 galls.

185. Mastics.—Mastic is the term applied to natural and artificial combinations of bituminous or resinous substances with other ingredients. They are used as cements to other materials, or as coatings to render them impervious to water. Artificial mastics have been formed by mixing vegetable tar, pitch, and other resinous substances with litharge, powdered brick, powdered limestone, &c., but the results obtained are generally inferior to those obtained from bituminous mastic, or *Asphalte*, which is a natural combination and is used for pavements, floors, roofs, covering walls and arches, lining tanks and drains, and covering the ground course of brick-work, &c, to prevent the rising of damp in walls. Natural asphalte consists of carbonate of lime intimately connected with bitumen. It is found in the neighbourhood of the Jura mountains, and is melted up with mineral tar so as to form a compact semi-elastic solid, well adapted to resist the effects of moderate heat and wet. It is laid down hot, generally over fine concrete, and detailed instructions for its preparation will be found in Vol. II., under the head of *Flooring*

186. Glazing.—*Glazing* is the art of fixing glass in the frames of windows. It is secured with putty, which is a tough tenacious paste, consisting of whiting and linseed oil, much improved by the addition of a little white-lead. The ingredients should be well beaten together for several hours. In India, putty is frequently made with chalk, resin (*rál*) and linseed oil. Turpentine oil is sometimes mixed with these ingredients, or wholly substituted for the linseed oil, to make the putty harden quickly.

Large panes of glass are also secured with small nails or "sprigs."

Glass is cut by means of a glazier's diamond. Care should be taken to bed the glass to be cut, on a soft thick yielding substance, which shall accommodate itself to any inequalities in the surface of the pane, especially with panes of any size. A straight edge is applied, and the diamond being drawn steadily along it, a smooth fissure or superficial crack is made, which should be continued without interruption from one end to the other of the line in which the glass is to be cut. The skilful work-

man then applies a small force solely at one extremity of this line, and the crack which he forms is led by the fissure almost with certainty to the other end.

187. Papering.—Rooms are seldom *papered* in India, except in dwelling houses in the hills: they could however easily be papered in most parts of the country, except perhaps in a damp climate like that of Bengal. The paste, with which the paper is attached, should be made with arsenic, to protect the paper from white-ants, &c., and of a thin consistency, just enough only being applied to ensure the adhesion of the paper; otherwise it will peel off.

One principal reason for adopting distemper for interiors of Indian dwelling-houses, in preference to papering them is the comparative ease and economy with which the white and color washed wall can be periodically cleaned and recolored, a measure often demanded on sanitary grounds. As now, however, a washable paper has been introduced into England (by the Amaranth staining company) one of the chief objections against papering interior walls in India is removed. The surface of this new material is non-absorbent, while it has the same dead unpolished appearance as the ordinary paper and is quite as cheap. Soap and water washing removes every form of discoloration and even a stiff brush does no injury to texture, color, or pattern.

SECTION II.—EARTHWORK.

188. The mere digging or cutting into the earth is so common and obvious an operation that it may seem to require neither skill nor explanation. This however, only applies to small and ordinary operations; for when the work is extensive, as in the formation of canals, reservoirs, tunnels, and the like, many expedients are resorted to that might not occur to common workmen; they have arisen out of experience, and are adopted because they economise labor and time, and consequently diminish the expense of executing the work.

In many countries, the mere mode of executing the work is of little or no importance to the Engineer; his duty being to set out the form of the work according to the plans previously prepared; and to see that it is properly executed. The reason of this is, that workmen may frequently be found, who will contract for the whole business, either at one specified sum of money, or for a certain price per cubic yard, whatever the work may happen to measure; and in these cases such workmen hire and pay their laborers, find all the necessary tools and materials, and execute the work in such manner as they believe will render it most profitable to themselves. The Engineer, in this case, has no care or trouble about the execution, nor should he interfere in it, unless he perceives something palpably wrong.

189. The usual course of proceeding, when contractors for the work can be obtained, is for the Engineer to prepare his map or plan of the country, together with a correct *profile* or section, to scale, of the intended work, and to write out a specification explanatory of his drawings and plans, stating how the work is to be executed—where the spare soil is to be deposited—when the work is to commence—what time will be allowed for its completion—how and where it is to be paid for—what penalty is expected to be incurred should the work be slighted, neglected, or not finished within the stated time—whether the contractor is to be kept free

from water, should springs be cut in the progress of his operations, or whether (as it is technically called) he is to bear his own water-charges—and any other particulars necessary to be known. These plans and particulars are then deposited in some accessible place, as near as possible to where the work is to be performed, or in a neighbouring town or city. Advertisements are then inserted in newspapers, or otherwise brought before the notice of the public, stating that certain works are required to be done, the plans and particulars of which are deposited for inspection and examination at a certain place, from some specified date to another; and inviting all persons who may be willing to contract for the execution of such work to inspect the plans, or the ground itself, and to send in sealed tenders to a certain place, on or before a certain day; in which *they are to state the price and conditions upon which they will undertake* the performance of the work. These tenders are opened by some authorized person, and the common course is to let, or give the work to the lowest bidder. Notwithstanding this is the usual practice, it is one that ought not to be universally adopted, because the ability of the contractor to perform the work, and his respectability, ought always to be enquired into. Many instances occur in which parties, from the hope of gain, will put in tenders, without being acquainted with the nature of the work, and will take contracts for its performance at prices lower than it can be possibly done for, although they perhaps neither possess the necessary implements, or capital to pay their men, or provide what is necessary for its execution; and notwithstanding they may give sureties under bond for the due performance of what they undertake, yet when they find it costs more than they are to receive for it, or that their operations are so unsatisfactory to the Engineer, that he will not pass their accounts for payment, abscond, leaving their sureties to suffer, or prove that they are not responsible. The Engineer has then to look out for other persons to finish his work, after much delay and vexation, and perhaps can only procure them at very advanced prices. The Engineer, from his knowledge and experience, ought to be able to judge of the value of what he means to execute, and should be consulted as to the tenders before any one is accepted; and he ought not to permit any tender to be accepted when he knows the price offered is such a one as will not allow the work to be executed in a good and substantial manner.

To form a specification, however, requires a sound knowledge of the

is sufficient to maintain the side either of an embankment or of a cutting at a uniform slope, whose angle to the horizon is the *angle of repose.* This is called the *natural slope* of the earth, and is the lowest slope, which soil thrown down freely and loosely, tends to assume and permanently to retain. The tangent of the angle of repose is the co-efficient of friction of the soil; and it is usual to describe the slope of earthwork by the ratio of its horizontal breadth to its vertical height, that is, by the ratio of the radius to the tangent of the angle the slope makes with the horizon; the greater this ratio, the greater the slope.*

The following are the observed angles of repose or natural slopes of several kinds of soil:

Earth.		Angle of repose.	Customary designation of natural slope.
Dry sand, clay and mixed earth, . .	from	37°	1·33 to 1
	to	21°	2·63 to 1
Damp clay, ...		45°	1 to 1
Wet clay, ...	from	17°	3·23 to 1
	to	14°	4 to 1
Shingle and gravel, ...	from	48°	·9 to 1
	to	35°	1·43 to 1
Peat, ...	from	45°	1 to 1
	to	14°	4 to 1
Mud, ...		0	0

The most frequent earth-slopes are those called $1\frac{1}{2}$ to 1 and 2 to 1, (the latter being generally *for depths exceeding 35 feet,) corresponding to* angles of repose $33\frac{1}{2}°$ and $26\frac{1}{2}°$, nearly. The presence of a small amount of moisture in the earth seems slightly to increase its friction; but any large quantity of moisture diminishes it, till the earth is reduced to a semifluid state. Hence to insure frictional stability, provision must be made for draining off the water contained in the earth.

* In describing the *longitudinal* slope of a road, a different usage *occasionally prevails.* Where a road is said to rise 1 in 20, properly speaking, it means that in a horizontal length of 20 feet the rise *is 1 foot; and in designing a road and drawing the section of it,* such would be the way of expressing the slope. But as it is usual in measuring the length of a road, unless the slope be very great, to lay the chain along the ground, whether or not it is absolutely horizontal, a rise of 1 in 20 has come to mean a *rise of 1 foot in a length of road of 20 feet,* that is the slope is expressed by the ratio of [illegible]

[illegible]

is far steeper than is usually met with in a flat country.

192. The property of retaining water and forming a paste with it belongs specially to clays, which, however hard when first dug, gradually soften and disintegrate by the action of the weather, and lose their frictional stability. Hence, slopes of cuttings through stratified clays vary from 2 to 1 to $3\frac{1}{2}$ to 1. Alternate strata of clay and sand are generally considered the very worst for excavation, as the sand favors the access of water while the clay prevents its escape.

All stratified materials occurring in layers inclining to the horizon in the same direction as the side of a cutting, are liable to a slipping of one stratum on another. And as it is evident that when strata are not horizontal, if a cutting be made through them, their dip must on one side or the other incline towards the cutting, it follows that horizontal strata are the most favorable for excavation.

Rocks have frequently a certain permanent cohesion; so that, when firm and sound, a cutting may be carried through them with sides vertical, or nearly so. How far this cohesion is to be depended on, is a question to be solved rather by observation of the rock in each case, than by any general principles having regard to its geological position, chemical composition, &c.; for its mechanical properties may have little connection with these. Generally speaking, however, the cohesion of igneous rocks such as granite, trap, quartz, &c., if they are not much fissured may be trusted, and they may be left standing at very steep slopes. Of sedimentary rocks, sandstone and limestone, whether compact or granular, if hard enough for building purposes, will stand with vertical or nearly vertical faces. Sandstone exists, however, of all degrees of hardness, and may require a slope as great as $1\frac{1}{2}$ to 1; while chalk will stand at from $\frac{1}{2}$ to 1 to $1\frac{1}{2}$ to 1, the cohesion of the upper beds being greater than that of the lower. All argillaceous rocks, such as shale, must be treated with great caution, for the reasons stated in the last paragraph.

CHAPTER VIII.

MENSURATION AND SETTING OUT.*

193. Mensuration.—The boundaries of a piece of earthwork in general are as follows:—

I. The *base or formation*, DE, in *Figs.* 1, 2 and 3, being a surface, nearly if not exactly horizontal, forming the bottom of a cutting, or the top of an embankment.

II. *The original surface of the ground, AB, forming the top of a* cutting or the bottom of an embankment.

III. The *sides or slopes*, AD and BE, connecting the base with the natural surface; *Figs.* 1 and 2, represent sections of cuttings, the former

Fig. 1.

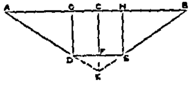
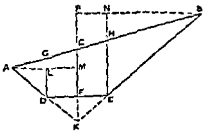
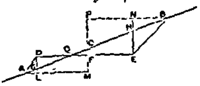


Fig. 2.



through level ground, the latter through "side long ground." If they be turned upside down they will represent embankments. *Fig.* 3, shows

Fig. 3.†



a piece of earthwork, part of which, QEB, is in cutting, and the other part, ADQ, in embankment. *C* is a point on the centre line of the base of the earthwork; and the horizontal dis-

* Most of the formulæ in this chapter are taken from Rankine's Civil Engineering. For equations (3), (5) and (7), I am indebted to Ensign Keay, Head Master, Upper Subordinate Class, Thomason College.

† In all these figures *DF* must be equal to *FE*, and the slopes *AD*, *BE*, must be the same.

tances, AC and BC, in *Fig.* 1, and AM and BP, *Figs.* 2 and 3, are termed *half breadths.* It will be evident that only in *Fig.* 1, is C in the centre, and the half-breadths in reality equal to each other; for although the half-breadths of the base DF, FE, are in all cases equal and the same, the remaining portions, AL and BN must vary with the slope of the ground, and must be determined by calculation.

194. SIDE WIDTHS.—For this purpose the following formulæ are given :—

In *Figs.* 1, 2 and 3, let the central depth of earthwork CF $= h$, the half-breadth of the base DF $=$ FE $= b$; let s to 1 be the slope of the earthwork, that is the ratio of horizontal feet to 1 vertical foot; r to 1 in a similar way, the slope of the side-long ground; $b' =$ horizontal half-breadth of the slope, that is BN on the upper side, and AL on the lower.

I. Then in *Fig.* 1—

$$b' = sh, \qquad (1).$$

$$BC = b + b' = b + sh \qquad (2).$$

II. In *Figs.* 2 and 3—

$$BP = r \times PC = s \times PK = s \times (PC + CF + FK)$$

$$\therefore PC\,(r - s) = s\,(CF + FK) = s\left(h + \frac{b}{s}\right) = b + sh$$

$$\therefore PC = \frac{b + hs}{r - s}, \text{ and } BC^2 = PC^2 + BP^2 = PC^2 + r^2\,PC^2$$

$$\therefore BC = PC\sqrt{(r^2 + 1)} = \frac{b + sh}{r - s}\sqrt{r^2 + 1} \qquad (3).$$

which gives the actual distance to be laid off from C to the upper edge of the cutting.

$$\text{Also } BN^2 \text{ (or } b'^2) = BH^2 - NH^2 = BH^2 - \frac{BN^2}{r^2}$$

$$\therefore b' = \frac{BHr}{\sqrt{r^2 + 1}}, \text{ and } BH = BC - CH. \quad \text{But } CH^2 = FE^2 + \frac{FE^2}{r^2}$$

$$\therefore CH = \frac{b\sqrt{r^2 + 1}}{r} \quad \therefore BH = \frac{b + sh}{r - s}\sqrt{r^2 + 1} - \frac{b}{r}\sqrt{r^2 + 1}$$

$$\text{and the half-breadth of slope } b = \left(\frac{b + sh}{r - s} - \frac{b}{r}\right)r$$

$$= \frac{rs}{r - s}\left(h + \frac{b}{r}\right) \qquad (4).$$

in which the factor $\left(h + \frac{b}{r}\right) =$ HE, the depth of earthwork at the edge

of the base. In the same way on the lower side of a cutting, or the upper side of an embankment, in *Fig.* 2—

$$AC = \frac{b + hs}{r + s}\sqrt{r^2 + 1} \text{ ....(5).}$$

$$\text{and } AL = b' = \frac{rs}{r + s}\left(h - \frac{b}{r}\right) \text{.............. (6).}$$

where the factor $\left(h - \frac{b}{r}\right)$ represents the depth GD.

When the ground intersects the base between the centre line and the edge of the earthwork, as at Q in *Fig.* 3, the values of BC and BN will be, as in *Fig.* 2, found from equations (3) and (4).

$$\text{Also } AC = \frac{b - sh}{r + s}\sqrt{r^2 + 1} \text{ .... (7).}$$

$$\text{and } AL = b' = \frac{rs}{r - s}\left(\frac{b}{r} - h\right) \text{ ....(8).}$$

where $\left(\frac{b}{r} - h\right)$ represents the height of the earthwork, GD.

The horizontal distance FQ $= rh$ .... (9).

It is evident that the above formula can be applied to cases in which the slope of the earthwork and of the natural surface of the ground is different on the two sides of the centre line, as well as to those in which they are the same. The distances AC and BC must be known to the person who actually lays out the work, while BN and AL are necessary for the calculation of its volume.

196. Section Areas.—*From the same data as are required to compute the breadths of the slopes, we may calculate the area of the cross section.* Using the same letters as before, and supposing S in each case to denote the area required :—

When the ground is level across, as in *Fig.* 1—

$$S = FC.GB = h\,(2b + b') = 2bh + sh^2 \text{ ....(10).}$$

When the ground has an uniform side-long slope not intersecting the base, as in *Fig.* 2—

S = area of trapezoid GDEH + triangle BHE + triangle AGD.

$$\therefore S = 2bh + \frac{rs}{2(r - s)}\left(h + \frac{b}{r}\right)^2 + \frac{rs}{2(r + s)}\left(h + \frac{b}{r}\right)^2$$

$$\text{or} = \frac{sb^2 + 2r^2bh + r^2sh^2}{r^2 - s^2} \text{ ....(11).}$$

The same quantity may also be expressed in the following manner, considering its area as the difference of the triangles ABK, DEK.

$$S = \frac{r^2 s}{r^2 - s^2}\left(h + \frac{b}{s}\right)^2 - \frac{b^2}{s} \text{ .... } (12).$$

This is a convenient formula for use in connection with a table of squares.

When the ground intersects the base, as in *Fig.* 3—

Here the cross section consists of two similar triangles, QBE and QAD, one in cutting, the other in embankment. Then QBE will be greater or less than QAD, according as Q is to the left or right of C, the centre point. When Q, C, and F, coincide, the triangles are equal, and the excavation is equal to the embankment. Let the area of QBE, the greater of the two as in the present case $= S'$; the area of QAD, the less $= S''$

$$\text{Then } S' = \frac{(BP + FQ)\,FH}{2} = \frac{(b + rh)^2}{2\,(r - s)} \text{ .... } (13).$$

$$S'' = \frac{(AM - FQ)\,DG}{2} = \frac{(b - rh)^2}{2\,(r - s)} \text{ .... } (14)$$

197. Volumes.—With the data obtained in the last two paragraphs, we have to calculate the volumes or quantities of earthwork in any given excavation or embankment.

Let $l =$ length of the portion of earthwork of which the volume V is required.

I. When two cross sections S_1 and S_2 are given, and the length between them, and when S_1 and S_2 are very nearly equal, *but not otherwise*—

$$V = \frac{S_1 + S_2}{2} \times l \text{ .... } (15).$$

II. When three equidistant cross sections S_1, S_2, S_3, are given, and whole length, then—

$$V = \frac{S_1 + 4\,S_2 + S_3}{6} \times l \text{ .... } (16).$$

III. When the length l and two cross sections S_1 and S_3 only are given, the area of an assumed cross section S_2 may be found approximately, by considering the central depth as a mean between the two end depths $\left(\frac{h + h''}{2} = h'\right)$ and the side-long slope of the ground as a *harmonic* mean between the two end slopes $\left(\frac{2rr''}{r + r''} = r'\right)$. Equation (16) may then be used; and the result will be found to be closer than what could be obtained from equation (15).

IV. When the ground is level across, this last process gives the follo ing result; h and h', being the depths at the two ends—

$$V = l\left\{\frac{b(h+h')}{2} + s\,\frac{h^2+hh'+h'^2}{3}\right\} \text{ .... (17}$$

$$\text{or } V = l\left\{\frac{b(h+h')}{2} + s\left[\frac{(h+h')^2}{4} + \frac{(h-h')^2}{12}\right]\right\} \text{ ....(18}$$

A formula convenient for use in connection with a table of squares.

V. When an *even* number (m) of equidistant cross sections, S_1, S_2, S_4,............ S_m, are given, and d the distance between each, then—

$$V = d\left(\frac{S_1}{2} + S_2 + S_3 + S_4 + \ldots\ldots + \frac{S_m}{2}\right) \text{ ....(20}$$

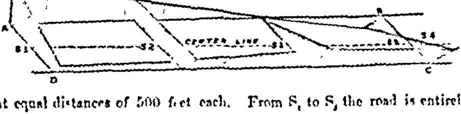
VI. Lastly, when an *odd* number (n) of equidistant cross sections, S S_2, S_3, ... S_n, are given, and d the distance between each, then—

$$V = \frac{d}{3}\left(S_1 + 4\,S_2 + 2\,S_3 + 4\,S_4 + \ldots 2\,S_{n-2} + 4\,S_{n-1} + S_n\right) \text{...(21)}$$

The term "Prismoidal formula," is applied to both the equations (16 and (17), which alone are strictly accurate. If an Engineer required t obtain approximately and quickly the quantities of cutting and embank ment in alternative lines or sections of a road or canal, he might ad vantageously use equations (20) or (21): but it must be remembere that they are but approximations, and in the case of constantly shiftin gradients, or naturally uneven ground might give very inaccurate re sults. For a thoroughly correct, final, estimate, the prismoidal formul should be used.

198. The following example will serve to show how the above formula are applied.

Let ABCD, be a piece of road on which the sections S_1, S_2, &c., are



at equal distances of 500 feet each. From S_1 to S_3 the road is entirely in digging, beyond that point it is partly in embankment; S_4 representing a section of the embanked portion at the line BC; at S_1 the ground is level across; at all the other sections it is side-long. Let b the half-breadth be 20 feet, and s the slope of the earthwork, be 1 to 1 throughout.

Let the central depths at S_1, S_2, S_3, and S_4, be 10, 6, 2 and 1 foot,

respectively, and the natural slope of the side-long ground at S_1, S_3, and S_4, be 70 to 1, 10 to 1, and 7 to 1, respectively.

I. Then at S_1, the horizontal half-breadths of the side slopes are (equations 4 and 5)

$$b' = \frac{70}{69}\left(10 + \frac{20}{70}\right) = 10\cdot43 \text{ feet on the side A,}$$

$$\text{and } b' = \frac{70}{71}\left(10 - \frac{20}{70}\right) = 9\cdot6 \text{ feet nearly, on the side D,}$$

and the area S_1 (equation 11)

$$= \frac{(1 \times 400) + (2 \times 4900 \times 20 \times 10) + (4900 \times 1 \times 10)}{4900 - 1}$$

$$= 500 \text{ square feet nearly; (equation 12)}$$

$$S_1 = \frac{4900 \times 1}{4900 - 1}\left(10 + \frac{20}{1}\right)^2 - \frac{400}{1} = 500 \text{ square feet, nearly.}$$

At S_2 we have (equation 1)

$b' = 6$, the horizontal half-breadth of the side-slopes, and (equation 10).

$S_2 = (2 \times 20 \times 6) + (1 \times 36) = 276$ square feet.

At S_3, in like manner, we have (equations 4, 6 and 11)

$b' = 4\cdot\dot{4}$ feet on the upper side, and $b' = 0$ on the lower side. And $S_3 = 88\cdot8$ square feet.

For the two sections on the line BC, we have for the half-breadth of the excavated slope (equation 4) $b' = 4\cdot5$ feet;

and the half breadth of the embanked slope (equation 8) $b = 2\cdot2$ feet nearly.

$$\text{Also (equation 13) } S_4 = \frac{(20 + 7)^2}{2 \times 6} = 60\cdot75 \text{ square feet.}$$

$$\text{And (equation 14) } S_5 = \frac{(20 - 7)^2}{2 \times 6} = 14\cdot08 \text{ square feet.}$$

199. II. Having calculated the areas of the cross sections S_1, S_2, S_3, S_4, and S_5, we may find the whole quantities of earthwork.

To find the volume of the excavation from S_1 to S_3 the true content will be (equation 16)

$$V = \frac{500 + 4 \times 276 + 88\cdot8}{6} \times 1000 = 282148 \text{ cubic feet.}$$

If we calculate the same value by equation (15) taking the sums of the volumes from S_1 to S_2, and from S_2 to S_3, we should have—

$V = \frac{500 + 276}{2} \times 500 + \frac{276 + 88\cdot8}{2} \times 500 = 285222$ cubic feet, an error in excess of above 3000 cubic feet. Or, if we had only the two sections S_1 and S_3 given us, and we wished to find the volume by as-

suming S_2 by the method shown in III., para. 197, we should have $h_1 = \frac{h + h'}{2} = 6$ feet, which is correct, and $r' = \frac{2r(-r')}{r + (-r')} = -\frac{2rr'}{r - r'} = -25$.

The negative sign being here used as one slope is directly in the opposite direction to the other; and the mean slope going with that which is steepest, that is, with the one in which r is less. From the above data we should find (equation 11) $S_2 = 276{\cdot}50$ square feet, only half a square foot greater than the real area, and from this calculation we should have—

$V = 282481{\cdot}\dot{3}$ cubic feet, an error in excess of only $333{\cdot}\dot{3}$ cubic feet.

In measuring the ground between S_3 and the line BC, we must take it in two portions, as it is partly in embankment and partly in excavation.

The embanked portion is merely a triangular pyramid having for its base S_3, and its height the distance between S_3 and $S_5 = 500$ feet; its content therefore will be $\frac{500}{3} \times S_3 = \frac{500}{3} \times 14{\cdot}08 = 2347$ cubic feet.

The excavated portion, which is a prismoid, may be found in several ways, of which the most accurate would be to assume an intermediate section in the manner shown above.

The volume of excavation thus obtained would be 31·749 cubic feet.

Equation 15 could not with any accuracy be applied for finding this volume, as the cross sections S_3 and S_4 differ so largely; it would give an error in excess of more than 5000 cubic feet. Nor would it give an accurate result to find the whole volume from S_1 to S_4 by equation 19, and then to deduct the portion S_1 to S_3 already found. For that formula is only applicable to a single prismoid, such as the volume is from S_1 to S_3; and the whole volume from S_1 to S_4 is made up of two distinct prismoids. From S_1 to S_3 there is one common half-breadth of 20 feet, but from S_3 to S_4 this half-breadth keeps diminishing from 20 to 13·5 feet, as may be found by calculation. So that the figures are in no way similar to each other.

To facilitate calculations of earthwork, many books of tables have been published, such as Sir John Macneill's, Bidder's, Bashforth's, and others, generally depending on some or others of the formulæ given in this Chapter.

200. Setting out.—In all cases whether contractors are employed or not, the Engineer is expected to set out his own work upon the ground for execution; so that the responsibility of its form or shape rests upon himself. This setting out is performed by driving stakes at the corners or angles, and

ABLES,

IN INDIA.

1.

LANATION.

20·0

.rapezoidal solid whose length is 100 feet, width 1 foot, and whose depths
tuns ; and are intended to be applied to the central part of any cutting ex-
l slopes whose heights are shown as before.

bles :

19·0

height in the left hand vertical column, and refer to the intersection of the

base of the cutting and the red figures by the ratio of the slopes, and the

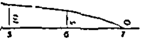
18·0

XAMPLE.

17·0

16·0

15·0



14·0

13·0

12·0

11·0

10·0

9·0

Heights.	a	b
0 } 14	700	6533
14 } 17	1550	24100
17 } 20	1850	34300
20 } 15	1750	30833
15 } 10	1750	30833
10 } 5	750	5833
5 } 0	250	833
Totals,	8100	118265

8100 × 30 = 243000 = content of centre.
118265 × 1½ = 177397 = „ slopes.

4.0397 = total content.

8·0

EXAMPLE.

10000 × 1 8 × 2 = 36000 required area.

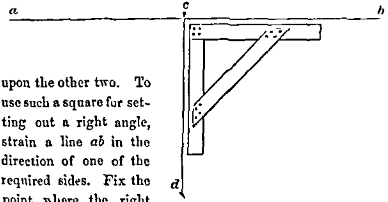
SLOPE TABLE.

R	N.
¼	1·03
½	1·10
¾	1·25
1	1·41
1½	1·80
2	2·23
2½	2·70
3	3·16
3½	3·64
4	4·12
4½	4·61
5	5·09
6	6·08

7·C	700 4900						
6·(	650 4233	600 3600					
5·(	600 3633	550 3033	500 2500				
4·(	550 3100	500 2533	450 2033	400 1600			
3·(	500 2633	450 2100	400 1633	350 1233	300 900		
2·(	450 2233	400 1733	350 1300	300 933	250 633	200 400	
1·(	400 1900	350 1433	300 1033	250 700	200 433	150 233	100 100
(	350 1633	300 1200	250 833	200 533	150 300	100 133	50 33
)	7·0	6·0	5·0	4·0	3·0	2·0	1·0

straining a line or cord from one stake to the other, to obtain right lines, which are afterwards marked by pegs or small stakes driven close to the line, before it is taken up to set out another length. Or what is much better, the line may be marked either throughout its own length, or at regular intervals by "nicking out," or by what in India is called making a *daghbel*, which consists in notching the ground along the line by means of a *phaora*, to a depth depending on the nature of the soil, the notch being less easily obliterated in hard, than in soft, soil.

When a square or right-angle has to be set out on the ground, as in digging the foundations for square buildings, or for forming square ponds or reservoirs, it may be done by the surveyor's cross, or by a theodolite, first directed to a picket-staff placed in the direction of one line or side, and then on turning the instrument a quarter round or 90°, the position of a second staff will be obtained; and the vertex of the angle will be at that point indicated by a plummet let fall from the centre of the instrument. The most usual method, however, of setting out right angles on the ground, is by an instrument usually possessed by workmen, or if not, that is easily made, called a *ground square*. It is merely two straight-edged strips of board about five or six feet long, the two ends of which are so united together as to form a right angle, (as in figure) and they are held in the position by another similar strip nailed diagonally



upon the other two. To use such a square for setting out a right angle, strain a line *ab* in the direction of one of the required sides. Fix the point where the right angle is to occur in that line, by driving a stake as at *c*, and fix another line to it. Then apply one side of the square close to, or parallel to the first line, letting the point of the square coincide with the stake; strain the other line close to the other side of the square, and fix its end to a

stake d; then reverse the instrument, and if the lines coincide, the square may be removed, and the right-angle indicated, may be marked on the ground. If otherwise, divide the angle formed by the two lines, and the line so dividing it will be the perpendicular required. If a number of other angles, differing from right angles, have to be set out for short distances, similar implements to that described, may be made for the purpose; but this will be unnecessary, unless they are numerous. In general, however, all angles that differ from right angles, are set out by the theodolite. Perpendiculars to any given line may also be set out on the ground by most of the problems by which they can be drawn on paper, using a measuring chain, tape, or knotted cord, in the place of compasses.

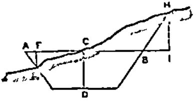
201. *Centre Line.*—In setting out a piece of earthwork such as a road or canal, the first thing laid down is the centre line. Pegs should be driven along it at intervals of from 200 to 50 feet apart, according as the country is level or hilly; the heads of these pegs should be flush with the ground, and the levelling staves should be placed upon them in levelling the centre line, which is the next thing to be done. To estimate the depth of excavation or the height of embankment required at each peg, a longitudinal section of the central line must be plotted on paper; and the *formation line*, that is, the surface line of the earthwork, to be executed, such as the surface of a road or the bed of a canal, must be drawn on this section. A little calculation will then show how many feet above or below the ground, the formation line will be at each peg. Having obtained this depth the half-breadths may either be calculated from the formulæ in para. 194; or they may be found as follows.

202. *To set out Side Widths.*—The formulæ given above for finding the side widths of any embankment or cutting, though useful in office calculations, would not be generally applicable in actually setting out either a Railway or Canal, for the two following reasons—1st, That ground is seldom found to fall with so regular a slope as to allow the formula to be used, since the least deviation from the slope that has been assumed, such as a hillock or mound, will throw the widths out; 2ndly, That as cross sections at each chain stump must be taken in order to find the slope (r in the formula), it is easier to plot the section, and take the side widths off by scale, than to investigate them mathematically.

There are two methods usually adopted in practice, their use depending a good deal on the nature of the ground. If the slope be so abrupt or

wooded, that one or two settings-up of the level will not command the whole length of the cross-section, it is perhaps easier to take the cross sections as best one can, and after plotting them, to take the side widths off by scale, and lay them down in a second operation on the field. But in any moderately level ground, the following method will be found by far the easier, involving as it does but one operation, and giving results as correct as the nature of the case admits.

Let the line EH represent the natural surface of the ground at the cross section; it will readily be perceived that the real half-width CF is much shorter than the horizontal or computed half-width AC, because the ground is depressed on that side; and the half-width CI on the other side, greater, the ground there being elevated. The problem is to determine exactly the distances CF and CI. First let us suppose the point E, or the distance CF, to be known, and that with a level we determine the difference of level between the points C and E, (*i. e.*, the line FE); then we have a small right-angled triangle AEF, of which EF is determined, being the difference of level, and the ratio of AF to FE is known; therefore the side AF is known, which subtracted from the computed half-width AC, gives CF, the required distance.



203. However, we have been supposing that the point E is known, whereas that point is the object of our search; in practice therefore we proceed thus:—

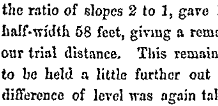
Take the computed half-breadth, and if the ground is depressed, let a levelling staff be held somewhat nearer the centre line than the computed half-width for an approximation to the point E: then determine the difference of level between this assumed point and the centre point C; multiply this *difference of level by the ratio of the slopes, and subtract the result* from the computed half-width. If the remainder be equal to the distance of the *staff from the centre line, our assumed point is correct; but if not*, the operation must be repeated till the two agree, or very nearly; remembering in our present case of depressed ground, that if the remainder is greater than the distance of our staff to the centre line, that the staff has been held too near; and *vice versâ.*

For example, suppose depth of cutting to be 20 feet, slopes 2 to 1, base

36 feet, and therefore the computed half-width CA, 58 feet; the ground being depressed, we estimated that the point E might fall short of the computed half-width 2 feet; we therefore directed levelling staff to be held at 56 feet from the centre stump C, at which point another staff was held, and by means of a level set up at a convenient distance, we found the difference of level between these points to be 0·87 feet, which multiplied by the ratio of slopes 2 to 1, gave 1·74 to be subtracted from the computed half-width 58 feet, giving a remainder 56·26 feet, which differs 0·26 from our trial distance. This remainder being greater, the staff was directed to be held a little further out at 56·20 feet from the centre, and the difference of level was again taken, (or rather we should say the staff was again read off, as the level had not been disturbed) and found to be 0·91, which multiplied by the ratio of the slopes gave 1·82 to be subtracted from 58 feet, leaving 56·18 for the second approximation, which differing only 0·02 from the trial distance, was adopted as the correct half-width for the depressed side.

When the ground is elevated above the horizontal line, as shown in the right side of the figure, the mode of operation will be precisely the same, except that, instead of holding the staff at *a less distance* than the computed half-width, it must de held at a *greater distance* to get the point H by approximation.

204. In the case of an embankment, the real half-widths being less on the elevated side, and greater on the depressed side than the computed half-widths, we must, in the former case have the staff held at a less distance, and in the latter, held at a greater distance, from the centre, than the said computed half-widths, in order to get an approximation to H and E; in all other respects, the operation is exactly the same.



The process above described may appear to the reader a very tedious one; it perhaps is so to read, but a little practice will convince him that it is a very expeditious method, for in most cases, one setting up of the level will answer for several stations, and the multiplications by the ratio of the slopes, upon such small numbers as mostly occur, are easily performed, especially if it be an even number, such as 2 to 1, 3 to 1, &c.

The columns of the field-book may be arranged as in the following

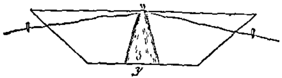
example, for making the calculations in the field, or may be abridged at pleasure:—

Number of chain stump.	Depth of cutting. Height of embankment.	Computed half-width.	Level Readings.			Difference + or −.		Difference ratio of slope + or −.		Required half-width.	
			Left.	Centre.	Right.	Left.	Right.	Left.	Right.	Left.	Right.
21	16 97	51 94	3 96	7·50	10 90	− 3 54	+ 3 40	− 7·08	+ 6 80	44 86	58 74

205. The most convenient instrument, not only for setting out road or canal work, but for measuring it when finished or in progress, is the rolling pocket tape; which, for this purpose should be divided into feet and inches on one side, and into yards divided into hundredths, and numbered at every tenth division, on the other. Such tapes are fitted up in leather cases, with a brass winch to wind them by, and a ring to pass the finger through and hold the tape at its extreme end. The ring counts into the measurement, and in using the tape the Engineer should retain the box in his hand, and give the ring to his assistant to hold against the point to be measured from, by which means he has the figures that give the result of the measurement constantly under his eye. The measuring tape is a most useful implement to the Engineer in many of his operations, and as the tape soons wears out by use while the leather box and winch are durable, every Engineer should know how to prepare his own tapes for renewal. The best and strongest thread tape (not cotton) should be procured, half or five-eights of an inch wide. This should be tightly stretched in long lengths between poles in the open air, in which position it is painted on both sides with white lead ground in oil, such as is used for house-painting, and left until it gets quite dry. It is then brought in and laid upon a long table for division by scale and compasses, and the divisions being marked in pencil, are afterwards finally put in with black oil paint, used with a pen made of a dry reed. The large divisions, such as feet, yards, &c., are usually marked with vermilion ground in oil, in order that they be more distinctly seen.

206. It is evident that although the central line of stakes by which a

road or canal has been set out must be regular, this can never be the case with the exterior or side bank stakes, which must always stand in irregular or zig-zag lines unless they are on perfectly level ground; notwithstanding which, the work set out by them will be straight and regular when finished, and brought to one uniform height. Indeed, the face of a country is often so altered by the excavations and embankments of large public works, *that its inhabitants scarcely know it, and the Engineer* himself would frequently be puzzled in the measurement of the work done, from his inability to distinguish between its former state and the recent alterations, were not certain marks made and left for this purpose. It is on this account that certain conical masses with grass and stakes on their tops, termed *bench-marks** by the Engineer, and *mutams* by the natives of *these provinces, are generally found standing in the middle of canals, reservoirs, and other excavations, particularly in uneven countries, in form like* y in the figure. Their use is to mark what was the surface of the ground before it was touched; for they are not built up, but consist of some of the former soil left standing by digging the earth away around them. The grass growing



upon them is the grass of the original surface, which having been untouched, continues to vegetate and prevents any deception being practised as to the actual former height of the soil, when the quantity of excavation is measured after its completion.

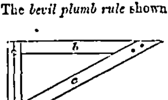
These little hillocks likewise serve to preserve the positions of the central line of stakes by which the work has been set out; for they are usually left round those stakes or round every second or third as may be necessary, so as to give the Engineer an opportunity of levelling at any future time from the original centre stakes, or measuring distances from them to the side banks, or taking the depth of the cutting. And they are never removed until the work has been measured, and is in such a state of forwardness as to render their longer retention useless.

It sometimes happens that the cutting or excavation for a road or canal is very deep, and wide at the top, as when a hill has to be passed through; *and in that case these bench-marks cannot be left, for their base would of*

* Not to be confounded with the bench marks used in Levelling.

necessity be so large as to block up the lower part of the work; in such places the surface of the ground can only be determined by carefully levelling it previous to beginning the excavation. For if any hollow or protuberance in the natural ground exists, either on a hill or any other place that has to be cut through, it may make a considerable addition to, or abstraction from the quantity of earth to be removed, and is frequently a source of dispute with workmen.

207. When the extreme sides or lines of a portion of earthwork have been set out, nothing more is necessary in order to produce the figure or form required, than to desire the workmen to proceed and carry up or down the slopes with an inclination of two to one, or any other degree that may have been previously arranged; but it may not be obvious how the necessary correctness of slope is to be obtained and preserved. This is done mechanically, either by means of an implement called *a bevil plumb rule, or by a clinometer.*



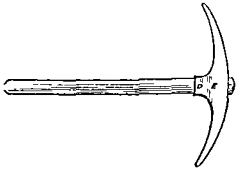
The *bevil plumb rule* shown in figure, consists of three strips of board *a*, *b* and *c*, framed together in the form of a triangle, the piece *a* being a common plumb rule and plummet, such as is used by bricklayers, and which being held upright, the piece *c* is so fixed as to represent the slope required for the bank, and *b* is merely a brace for retaining the other two pieces in their proper angular position, and therefore need not make a right angle with *a*, though it will be better that it should do so, because the implement then becomes useful for other purposes. For instance, it may be used as a ground square, as in figure page 231, and by having a large hole for the bob to play in at each end of the plumb rule, the instrument may be reversed by making *b* the bottom rail, and then it becomes a useful level for testing the level parts of the work. The sloping side *c*, ought to be at least three feet long; and separate instruments of this description will be necessary for each particular slope, if more than one should be adopted. Having such an instrument, there will be no difficulty in giving the necessary slope to the banks. Thus, in *Fig.* 1, page 216, suppose A to be the exterior stake at which the slope is to terminate. The workman begins by opening a hole of about a foot or eighteen inches wide between A and G, taking care to give sufficient slope to the side AD; when deep enough, say a foot or two, the lower point of the

CHAPTER IX.

TOOLS AND EXECUTION.

211. The implements required for the execution of ordinary earthwork may be divided into three classes. 1st, Those required to loosen and detach the soil from its natural position; 2nd, Those required to raise the loosened soil from its bed, and place it in (3rd) the vehicle for removing it, and depositing it where it is wanted.

Digging Tools.—Where the soil is loose, the same tool which detaches it may be used to raise it and put it into the vehicle required to move it. A spade, shovel, or the large bladed hoe, termed a *phaora*, will do for either of these works.



Pickaxe.—Where the soil is stiff and firm, it must be broken up by a more powerful tool; and for this purpose a pickaxe is used, made of iron with two points of steel welded on to it, and bent into the form shown in the marginal figure. For ordinary excavation it should be double ended, with an equal quantity of metal in each end, so as to balance well in the hand. Two feet from point to point is considered the most convenient length, and the metal should not weigh more than ten or twelve pounds; if heavier, it fatigues the workman without an equivalent advantage in work, and most men prefer this tool chisel-pointed, and about an inch wide, instead of being quite sharp. The common fault in pickaxes as usually made, is a want of sufficient depth and strength in *the eye* or socket

through which the wooden handle passes, for in this place they usually fail or break. The side plates that form the eye, ought not only to be thick for strength, but should be *at least* three and a half or four inches from D, to E in order to admit of the handle being well fixed; for the operation of this tool is a wrenching one, and unless this construction is attended to, the handles are constantly breaking or getting loose, which proves very troublesome. Pickaxes frequently require sharpening and repairing; if therefore there is no blacksmith in the immediate vicinity of the work, a portable forge should be provided to accompany it.

212. The *shovel* most approved is what is called heart-shaped, as shown in figure, instead of straight-edged, though some of both sorts are useful; they are sometimes used with a long handle, but the crook handle as shown in the figure, is a stronger and cheaper form. For actual digging upon the surface, particularly in clay or soft ground, a scoop tool, of the form shown at *Fig.* 2 is preferred. It is made like a common garden spade bent into a curved form, and in using it, it is advantageous to have a tub, or puddle of water formed, into which the tool is frequently dipped, to prevent stiff clay or loam from sticking in the hollow of the scoop. In using a shovel or spade of any sort, the foot must of course be protected by a shoe or wooden soled sandal. Natives of the Punjab use the spade in preference to the *phaora;* and Hindoostani Sappers and Miners dig well with it. It might probably be introduced without much difficulty into all parts of this country.

Fig. 1.

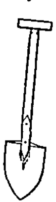


Fig. 2.

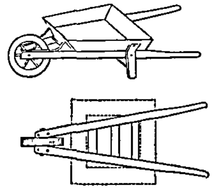
213. *Under-cutting.*—The ordinary process of digging consists in loosening the soil upon the surface, and taking it up by single shovel or spades-full, which "navigators" (as the best class of skilled excavators are called in England) term, underhand working; but they adopt also a more expeditious method of proceeding, called under-cutting, by which much labor is saved. The first hole or opening must be made in the ordinary manner, but instead of working on the surface and digging over it one spade deep, and then beginning and taking another spade's depth, they go to the full depth of the work, provided it is not more than six or

seven feet; taking care to form the sides to their intended slopes, but keeping the front or side, on which the excavation is to proceed, nearly perpendicular, or without any slope at all. The bottom of the hole being levelled and tried, the lower part of this front or breast, as they call it, is undermined or dug away by the pickaxe and shovel, to about a foot from the bottom, keeping the bottom as level and as nearly in its proper range as possible. The side slopes are treated in the same manner, or worked into the front about the same depth, the consequence of which is that a large mass of the earth of the front remains without any other support than that which it derives from its cohesion or adhesion to the earth behind it, and large masses therefore first crack or separate, and fall. If they do not separate as readily as the workmen wish, two or three large wooden wedges, shod with iron, are carried to the surface, and being placed a foot or two behind the front or breast, are struck with heavy wooden mauls, and this never fails to detach large masses of the soil; which, by the concussion of their fall are broken in pieces sufficiently small to be taken up into the barrows for removal. This, though an expeditious process, is one that is attended with some danger to the workmen; and therefore requires to be conducted with care. For the cracks or fissures that always precede the detachment of a mass of soil, are sometimes unseen or unheeded by the workmen, and masses fall when they are not expected to do so, and crush or maim the men beneath. On this account a front or breast, of more than about six feet, should not be so worked; but, when the work is deep, the upper breast may be kept four or five yards in advance of the lower one, with a flat surface between for the soil to fall upon, and deep cutting is almost always so conducted.

214. The *phaora* is too well known in this country to require much description. As it is wielded entirely by the arm, the laborer requires no protection for his foot, as he does in using a spade or shovel; as in the case of the pickaxe it is apt to give way at the socket through which the handle passes.

215. Wheel-Barrows.—The common form of wheel-barrows, with boarded sides, will not answer at all for the work of excavation, such barrows being too heavy in themselves, and very inconvenient for inverting to discharge the soil. The best form, and that constantly used in England for this work, is shown in the marginal figure; it is very shallow,

not exceeding 6 inches in depth, its four sides splay open, or make angles of about 45° with the bottom, in consequence of which the soil is very easily discharged from it; but its principal advantage is in the shortness



of the axis of the wheel, (which should be of cast-iron,) which allows a facility of turning out the contents that cannot be obtained if the axis is long. The frame of the barrow is constructed, by mortising three cross bars strongly into the two side rails which form the handles, and come so close together at their opposite ends as just to admit the wheel between them. The box of the barrow is separately made and fixed on to its place, as indicated by dotted lines in the figure, by screw bolts, with nuts underneath; and, as the box soon wears out by use, one frame will last for several successive boxes. The pivots of the wheel run in iron eyes, fixed by screw bolts under rails, so that they likewise, can be removed when worn out. A barrow of this kind, shallow as it may appear, will contain quite as much soil when heaped up, as a man can convey with convenience, when working throughout the day. And the mere frame of the barrow, without its box, is very useful for conveying flat building stones, or short pieces of timber, that will lie on it with convenience.

Barrows of the above kind were employed on the Ganges Canal works at Roorkee. The natives used with it a shoulder strap to ease the muscles of the arm.

The barrows should not be wheeled upon the ground, but 3-inch planks should be used to form level tracks or inclined planes to run them upon; and for this purpose, when the plank, or one or both of its ends cannot rest upon the ground, they are propped or raised to the required height and inclination by blocks, or a kind of stool with long legs, called tressels or horses. Planks of about 20 feet long are preferred when they can be used, not only to obviate a frequent repetition of joints, but because they are more easily fixed and supported. The bearings should not, however, be too distant, because a plank should not spring or vibrate while the loaded barrow is running upon it. If it does so, it should be propped

or blocked up in its central part. The slopes or inclined planes, formed of wheeling planks, should likewise be made as flat as possible, for it fatigues the workman less to run a greater distance on a gentle slope, than a short distance on one that is steep; their steepest inclination should therefore not exceed 1 in 12, unless the men are assisted by means of ropes and winding machinery.

216. The usual distribution of hands in shifting earth, is to employ *two at the immediate excavation to dig and to fill; that is to say, one with* a pickaxe to loosen and break down the soil, and the other with a shovel to fill a wheel-barrow that stands upon the end of a wheeling plank close to the work. Should the soil, however, be very loose, one pickman may be enough for two shovellers; or on the other hand should it be very stiff, one and a half or two pickmen may be required for one shoveller. Another man carries away the loaded barrow and takes it a stage along the plank, till he meets a second wheeler returning on the next stage with an empty barrow. At the termination of each stage, the planks are laid in a double line for a short distance, in order that the full and empty barrows may pass each other without interference. At the end of the track too, where the barrows are filled by the shoveller, there are two lines of planks laid in the form of the letter Y, so that the full barrow may be on one flank while the empty one is on the other, and they are wheeled when full alternately, up one, and down the other, plank, till they reach the single track where the earth is to be deposited. If a long bank has to be made, several planks should be laid in a radiating form from the single one, in order to distribute the earth by carrying it first along one, and then another. By the above arrangement every man should be at his post when wanted, either with a full or empty barrow, and a line of hands of any extent may be kept up regularly at work without a man standing idle for a moment.

The proportion of wheelers to shovellers is generally estimated in England by considering, that a shoveller takes about as long to fill an ordinary barrow containing 1 cubic foot of earth, as a wheeler takes to wheel it full a distance of about 100 or 120 feet on a horizontal plank, and to return with it empty. If the full barrow has to be wheeled up an ascent, each foot of rise is to be considered as much as six additional feet horizontal.

The number of barrows required for each shoveller is one more than the

number of wheelers. An English shoveller will lift 500 cubic feet of earth in a day, but a native workman cannot be depended on for more than one-fourth of that amount.

Barrow and plank wheeling is always expensive, and on this account it should never be made use of where the *length of lead* (as the distance the earth requires to be moved is termed) exceeds three or four stages. For greater distances, especially on nearly level ground, it will always be found most advantageous to cart the soil by one horse carts, built for the express purpose. The kind of cart most approved has only three wheels, two being behind and one before, the reason of which is that such carts stand firmly upon uneven ground, and will support themselves without aid from the horse; they are light and easy of draught, and they turn in a smaller space than any other construction of cart. The frame or carriage part, to which the wheels are attached, is independent of the body, and is fastened to it by a pivot bar, very little beyond the centre of gravity of the body when loaded, so that a very small exertion of strength is sufficient to tilt the body up, and cause it to discharge its load. The trace-chains hook on indifferently before or behind, so that either end of the cart may be made to proceed. One such cart carries about as much as twelve wheel-barrows, and its average speed in going and returning is about $\frac{1}{6}$th more than that of a barrow, so that each cart is equivalent to about fourteen wheel-barrows in motion. In the formation of roads where small protuberances of soil have to be cut off, and probably carried a long distance to fill up hollows for obtaining a uniformly even surface, such carts are very useful.

217. Tilt Wagons.—In all cases where the work is sufficiently extensive, trucks or wagons running on iron rails should be used, propelled by men, horses, or locomotive engines.

Tilt wagons are of a variety of forms, some called *side-tip* or *side-tilt* wagons, which throw their load of earth to right or left of the line; others called *end-tilt*, which deposit it in front or rear, and others again which, by means of a circular turn-table under the body of the cart, can be made to project their load at pleasure to any side. Another variety is used when the earth has to be brought along at a height above the level on which it is to be laid down in layers, and when a temporary scaffold with a line of rails carrying the earth cart is run out from the completed portion of the work over the part in progress. The body of the wagon fre-

quently employed under such circumstances is made to invert entirely, throwing its load down vertically between the rails on the work below.

Where the enbankment requires to be only a little broader than the rails on which the wagon runs, as in ordinary railway works, the rear or front tilt wagon is the one generally employed. But where a broad massive enbankment has to be make, it is often better to use a side-tilt wagon to empty the earth right and left.

In England the best size for earth wagons is considered to be large enough to hold about 2 to 2½ cubic yards, or from 2½ to 3 tons weight of earth.

The wheels ought to be 3 feet in diameter; about 3½ cwts. of iron are employed in such a wagon, its whole weight being from 1 to 1½ tons. Each wagon carries about as much as fifty wheel-barrows; and its speed when drawn by a horse may be taken as about one-fifth greater than that of a barrow, so that one wagon is equivalent to about sixty barrows. In ordinary soil it has been estimated that one wagon going and returning a distance of about 6,000 feet, will keep one shoveller at work. If loaded wagons have to be drawn up an ascent and the temporary rails be good, each foot of rise is equal to about 150 feet of additional horizontal distance.

In calculating the number of horses required for earthwork where wagons are employed, the force which one horse can exert when walking slowly on a level plain is taken in England at about 120 lbs.; for the small horses of this country some deduction would require to be made from this amount, and probably 90 lbs. would be sufficient. The friction along temporary rails may be taken at 15 lbs. per ton, or about $\frac{1}{150}$th of the whole load. If we consider, therefore, that a loaded wagon weighs in all 4 tons, the force of traction to be exerted will be 60 lbs.; and one strong horse will be able to draw two wagons. We shall have, therefore, two wagons, one horse, and one man to go with the wagons, to carry to a lead of 6,000 feet, as much as one pickman can excavate, and one shoveller put in a wagon.

218. Scoop.—In removing surface earth to a moderate distance, an implement called a *scoop*, serving the purposes of the shovel and the wheel-barrow combined, is used in America, and in some parts of India. It consists of a large open box like a hand-barrow, but having three sides only instead of four, and the bottom projecting with a sharp

edge, to the front. Being dragged along by two horses or bullocks, it is made to scoop up the earth from the surface at its open end, and to convey it along. The attachment of the two chains or ropes by which it is dragged, is about the middle of the scoop, and it is provided with two handles to the rear by which it is guided, and which being slightly raised by the hand of the driver, on reaching the point where the earth is to be laid down, the front edge which is armed with iron catches in the ground, and the horses moving on, the scoop is overturned. It can only be used of course when the earth is tolerably soft and loose. To facilitate excavation of ground having a stiff or hardened surface, it is frequently ploughed before setting the diggers to work.

In this country, when the work is not on a very large scale, and the lead not very great, it will generally be most economical to use baskets in preference to any other vehicle. The basket is the natural carrying implement of the native; so it requires no teaching to instruct coolies in its use, as the wheel-barrow does. Baskets are also easily obtained everywhere, at a very small cost, whereas the price of a barrow is considerable.

219. Cost of Earthwork.—From what has been written it will be seen that the cost of earthwork must depend—1st, On the price of labor; 2nd, On the nature of the soil; 3rd, On the length of lead, or distance the earth has to be carried; 4th, On the depth or height it has to be excavated or embanked. The price of labor depends on so many things that no general rules can be given for it. Each district has its own rate, which the Engineer must find out before preparing his estimate. It can only here be roughly stated that the price of earthwork in Upper India, now varies from Rs. 2 to 6 per 1000 cubic feet, according to locality, and details.

On the nature of the soil will depend the amount which a man can execute in a day. In some districts it is difficult to get a coolie to dig more than 50 cubic feet a day, but a native contractor will generally get far more work than that out of a man. It was found in digging the upper portions of the Ganges Canal, where the earth had to be carried on an average 150 feet, that three able-bodied men would dig and carry out in baskets 250 cubic feet per day, when the digging did not exceed 10 feet in depth. These men earned each 2 annas daily; and paying their laborers at this rate, the contractors agreed to dig the canal at Rs. 1-14

per 1,000 cubic feet down to 10 feet deep, and at Rs. 2-6 beyond that depth. The actual rates at which the work was done, including levelling and smoothing off the embankments, and deepening the berms and slopes, were Rs. 2 and Rs. 2-8 for depths less than, and exceeding, 10 feet, respectively. In the Cawnpore division of the canal, where the lead was not more than 50 feet on an average, the cost occasionally was as low as Rs. 1-8 per 1,000 cubic feet.

Each contractor used to undertake a portion of from 50 to 100 feet in length of canal channel, and give it out to sub-contractors or laborers, who engaged to do a daily task at fixed rates, the contractor finding the the tools. Much of the work was done by "Oodes," a class of excavators well known in the Upper Provinces of India, who wander about wherever they can get work and pasture for their cattle. These men generally use donkeys for the purpose of carrying earth.

220. Much valuable experience in earthwork was gained in the formation of the great Embankment for the Solani aqueduct, on the Ganges canal. The earth was first carried in wheel-barrows on planks, the length of run being from 200 to 300 yards, and the laborers receiving Rs. 4 per month. This work cost from Rs. 3 to 5 per 1,000 cubic feet; and as the length of lead was always becoming greater, it became necessary to employ wagons on rails. 450 side-tilt wagons were consequently used, each carrying from 45 to 50 cubic feet of earth, or from 30 to 33 cwts. The average cost of a wagon was Rs 358. These wagons were for a long time propelled by men; four beldars were told off to each; one remaining to dig and loosen the earth, while three worked the wagon; and all four digging and filling between trips

Filling one of these wagons occupied two men from 50 to 60 minutes, the earth being carried 30 feet on an average Although it was found just as cheap to employ men as horses in propelling the wagons, the latter were ultimately used, as laborers were not easily got in the large number required for such a great work. When horses were used, two beldars were told off to dig and load the wagon; and one horse drew two, and a man accompanied each horse. A horse was found to travel 2·85 miles per hour with a load, and 3·25 miles with an empty wagon.

Mr. Parker, in estimating the value of wagon labor with men and horses, has from a series of five months' accounts, in which are included the charges for excavating and carrying 1,317,000 cubic feet of earth,

abstracted the following tables. The first when the wagons were pulled by horses, the latter when they were pushed by men:—

TABLE I.—AVERAGE OF LABOR required for 1,000 cubic feet of digging, and carrying the earth in wagons drawn by horses to a mean distance of 9,200 feet by railway.

Description.	Average number.	Remarks.
Mates of beldars, ...	0·33	From this Table we find that 108 cubic feet is the day's work of a digger, and 352 cubic feet that of a horse.
Diggers, ...	9·23	
Horses, effective, ...	2·84	
Ditto in hospital, ...	0·40	The diggers have also to carry the earth in barrows a mean distance of 40 feet, in order to fill the wagons.
Ditto non-effective by Sundays, holidays, and rain, ...	0·70	
Men on scaffolding and greasing wagons (beldars), . . .	0·72	
Do., carpenters, ...	0·08	

TABLE II.—AVERAGE OF LABOR required for 1,000 cubic feet of digging, and carrying the earth in wagons pushed by men, to a mean distance of 8,700 feet by tramway.

Description of workmen.	Average number.	Remarks.
Mates of beldars, ...	0·56	From this Table we find that 50 cubic feet is the day's work of a man digging and carrying.
Diggers and carriers, ...	19·70	
Men on scaffolding and greasing (beldars,).	1·00	
Do., carpenters, ...	0·16	

The cost of digging and carrying 1,000 cubic feet of earth, as in the last table, was Rs. 3-13-0, which includes payment for Sundays, when no work is done. Had Sundays not been included, the cost to Government would have been Rs. 3-3-0.

In the same manner, the cost of digging and carrying 1,000 cubic feet of earth, as in Table I, was Rs. 3-12-0, detailed as follows, viz.:—

	R.	a.	p.
Superintending, - - - -	0	1	10
Digging, - - - - -	1	9	4
Carrying by horses, - - -	1	10	2
Greasing and oiling wagons, -	0	2	2
Scaffolding, - - - - -	0	4	6
Total Rs., -	3	12	0

which includes payment for Sundays. Had Sundays not been included, the cost would have been Rs. 3-2-0.

A locomotive steam engine was also employed for sometime on the Roorkee works, but it was not found an economical moving power. It also proved inconvenient, as it required a line of rails all to itself; since it was not safe to use it on the same line as horse wagons.

The rails on which these wagons ran were inclined at a slope of 1·5 feet per mile, down which the wagons carried their load, returning empty. They were formed partly of $\frac{1}{4}$ to $\frac{3}{4}$-inch bar-iron, screwed down to longitudinal sleepers, which were held in position by cross bars. Afterwards light English rails were used weighing 26 lbs. to the yard, which were laid much in the same way as the others. These English rails were found decidedly superior to the others, causing less friction and wear upon the wheels. But they were considerably more expensive to begin with, and could not be so easily replaced as the bar rails.

221. Boring Tools.—It is frequently desirable to know the nature of the soil some distance below the ground. As for instance, when a deep cutting has to be made, unless he knows whether he will be required to dig out soft sand or rock, the Engineer can form no estimate of the probable expense of the work. Nor can he calculate what will be the cost of a bridge until he knows how deep he will have to sink the foundations to obtain a firm substratum.

The usual method of obtaining this knowledge is by boring a vertical hole of $3\frac{1}{2}$ to 4 inches diameter, and bringing up specimens of the materials met with at various depths. The knowledge thus acquired is not wholly to be depended on; as the specimens brought up are crushed by the action of the boring tool, and sometimes reduced to paste by the water poured into the hole to keep the tool cool, and help its working. It may happen too that the tool may bring up a solitary specimen of boulder on which it has alighted, and convey the impression that it is passing through a stratum of them.

The ordinary boring tools are the *auger*, the *worm*, and the *jumper*. These are made of wrought-iron, steeled at the points and cutting edges. They are about $1\frac{1}{4}$ foot long, welded on to an iron bar or shank of about an equal length, and $1\frac{1}{8}$ inch square. At the top of the shank is a screw, connecting it with the *lengthening rods*. These are square bars usually about 10 feet long, of the same diameter as the shank, with screws at their ends

by which they can be joined together, to any length required. The uppermost rod is capable of being hung by a swivel and rope from a triangle or shears set over the boring hole, in order to haul up the rods.

The *auger* which is used for all ordinary earths, shale, and soft rock, is formed like a hollow cylinder, about 3½ inches in diameter, with an open sharp edged slit along one side of it. It is slightly contracted at the lower end, and sometimes has a small special point like a gimlet for boring in soft rock. It brings up specimens of the earth in the inside of its cylinder.

The *worm* is a sharp-pointed spiral, used for boring rocks too hard for the auger. After the worm has pierced the rock, the auger enlarges the hole and brings up the fragments. Both the auger and worm are worked by turning them continuously round towards the right, by means of a cross-head, about 6 feet long, driven by men.

To pierce rock too hard for the worm, *jumpers* are used, *see* para. 19. They are of various figures, some flat like a chisel with a sharp edge at the lower end; some square with a four sided point; and some spear-pointed. The jumper is worked by raising it to short distances, and then dropping it, twisting it half a turn round after each blow. It is sometimes simply hung by a rope instead of by lengthening rods. The auger is afterwards sent down to bring up specimens. In boring through very soft ground a series of iron pipes are sometimes pushed down to keep the hole open; these may be made to screw one to the other, so that they can be hauled up again.

CHAPTER X.

CUTTINGS.

222. In the last Chapter, the general operations of earthwork, which are common alike to cuttings and embankments, were described. In this Chapter it is purposed to describe those specially relating to cuttings.

It must first be observed that as a general rule, it is desirable to make the cuttings and embankments on a line of road, canal, &c., equal in cubic contents. The object of this is obviously that the earth obtained from the excavations should be made use of, and should just suffice, for the necessary embankments. In the case of roads and rail-roads, excavation is required at some parts of the line, and elevation of the road by embanking, at others. The depth or height of each, respectively, become in a measure fixed, when the *direction* of the line has been determined, and are thereafter to a very limited extent only, at the option of the designer; so that exact conformity to the rule above given, even when some variations in the width of the works are adopted, with the view of effecting what the fixed levels will not admit of, becomes a matter of some difficulty if not impracticable.

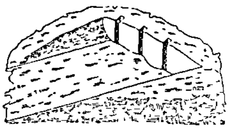
In the case of canals, excavation and embankment generally proceed side by side, and the banks not being necessarily, with reference to the purposes of the canal, of any fixed height and breadth, may have their dimensions regulated simply by the amount of excavation. This is on the supposition that the banks form no part of the water channel, the latter being altogether below the original surface. It is not, however, always so. Where the ground is low, the channel may be partly in excavation, partly bounded by the side banks. A lower level of country may require the bottom of the channel to be on the surface of the ground, its sides being altogether formed by the embankments. Or again it may happen that the whole must be raised above the level of the ground, the bottom as well as the sides being of "made earth." In the last two cases, there being no excavation at those parts of the line, provision must be made, just as in the

case of road and railway embankments, for obtaining the requisite amount of earth from elsewhere. It will accordingly be arranged if practicable in laying out the line, that some adjoining parts, traversing high land and requiring to be lowered, shall supply from their excavations the quantity of earth required for the embankments. When this cannot be managed, or not to the required extent, the earth must be procured from what are called *side cuttings*, excavations made for this purpose on either side of the line. When an excavation supplies more earth than is required for the embankments, the superfluous quantity is laid down in a line, generally parallel to the main work, in any convenient position; and this is technically called a *spoil bank*. Cases often occur, however, and especially in a country like India where land is cheap, in which it is more economical to make an embankment from a side cutting close at hand, than to bring the earth from a distant cutting; or, on the other hand, it may be cheaper to throw part of the material from a cutting into a spoil bank than to carry it to a distant embankment. These points must be decided by the Engineer, to the best of his judgment in each case.

In England, previous to opening a cutting, it is usual to strip off the upper soil or vegetable mould from the ground to the depth of from 3 to 6 inches, and to preserve it for the purpose of resoiling the slopes, in order that grass may grow on them readily If the cutting happens to be through grass land, the sods of turf are taken off and kept rolled up with the grass inside in a moist shady place. In this way they may be preserved for some time, and take root readily again in the new slopes.

223. A cutting in a hill side of considerable height is usually begun, if the earth will stand for any time with vertical sides, by cutting a fair vertical face to the work at right angles to the direction of the cutting. From this face, vertical niches, as shown in the figure, are made, wide enough for one man to ply his pickaxe, after which very little labor is required to separate the masses between the niches, the earth in the meantime being carried off by baskets, barrows or wagons. In cutting into a vertical face, one excavator to a breadth of 5 or 6 feet, is about as close as men can work without getting into each others way.

Fig. 3.



Figs. 1 and 2, *Plate* XXIII., show the consecutive operations required for heavy cutting; the cutting being supposed to start from the left. As the work proceeds into the hill, and the width is increased to provide for slopes, it becomes desirable to run a *gullet* or vertical excavation wide enough for one line of temporary rails along the centre line, in order to bring the greatest number of wagons into use. The wagons in the gullet are filled either directly by diggers in front of them, or by barrows on both sides, working on a stage above them. As the height of the hill increases, side tracks are laid down on this second stage inclining down to the lower level. On these lines the full wagons descend on one side, and the empty ones ascend on the other.

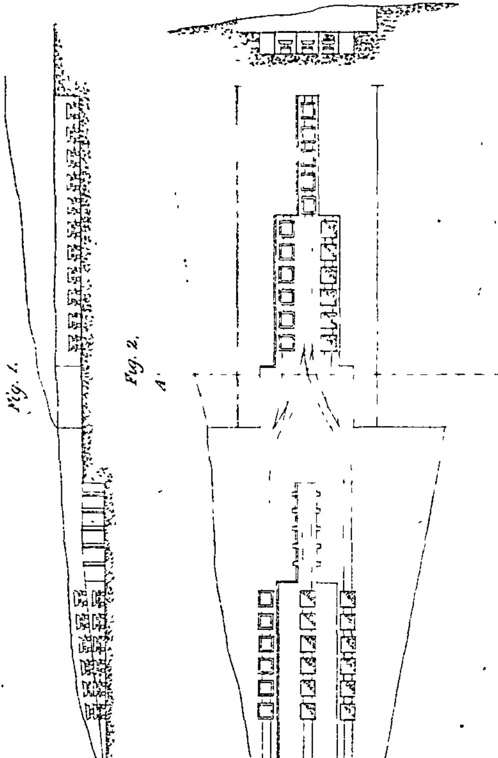
In executing a cutting in this manner, the bed should always be kept inclined upwards; so as to allow of any water which may collect at the bottom, being easily conducted out to the end of the work. This should be done irrespective of the slope which the formation bed is finally to receive; as it may easily be adjusted after the cutting is carried right through the hill.

It is evident that many cases might occur where the above mode of operations could not be followed, as it might be necessary to remove the earth up out of the excavation to the level of the ground. This might for instance be the case where a railway had to be carried through a long cutting; and to save time it might be necessary to open ground at intermediate points as well as from the two ends. This, however, would not often happen, as the expense would of course be very much increased by such a proceeding. In forming canals, however, in a flat country like India, it is almost always necessary to raise the earth up from its bed, as in but few cases would it be possible, or at least desirable, to bring out the bed of the canal any where to the level of the country.

224. *Horse Run.*—When the bank up which soil has to be moved is necessarily very high and steep, as for example, if it should make an angle with the horizon of 30° or 40°, and is perhaps 40 or 50 feet high, an expedient called a *horse run*, is sometimes resorted to. That is, two tracks of planks are placed upon the slope, and fixed there by stakes driven into the ground and nailed or spiked to the planks. These tracks should be placed at a distance asunder that rather exceeds the depth of the excavation. Opposite the top of each track a post, with a large iron sheave or pulley fixed to it, is firmly let into the ground. The wheel-barrows used are of

CUTTINGS.

Section on A A.



the same constructions as those before described, but much deeper and larger, and a strong iron staple is fixed in the front of each for receiving the hook of a rope passing from the barrow in the bottom, up the slope through the two sheaves, and terminating in a hook at the second barrow upon the top of the slope, in such manner that the upper barrow cannot be lowered without bringing up the lower one, and *vice versâ*. A straight horizontal horse-track is formed just behind the posts, extending from one to the other of them, and a strong iron ring being lashed to that portion of the rope that is constantly between the two posts, the traces of a horse are hooked into it, and as the animal is driven backwards and forwards, he will elevate one and depress the other of the barrows alternately. The lower barrow being detached from its rope, is placed where it may be loaded with soil, when it is wheeled to the foot of the inclined plane, and the rope being hooked on to it, a signal is given to the driver above to start the horse, when he draws the loaded barrow up the slope, a man following behind at the handles to guide it, and keep the barrow legs above the ground. While the loaded barrow is thus ascending, the empty one descends, guided in like manner by the man who had before accompanied it upwards, his weight and that of his barrow compensating nearly for the man and barrow ascending on the other track. The ascending man has to walk in a direction nearly perpendicular to that of the inclined plane, so that he can exert no strength or muscular action to assist the barrow in its ascent; but, on the contrary, a large portion of his weight is added to that of the barrow; but this is compensated by the descending man, who comes with his face forwards, and by hanging on to the arms of his barrow, throws his weight upon it so as nearly to equalize the weight of the ascending barrow.

The horse run is a slow and expensive method of raising soil, and one that should not be resorted to except in cases of necessity; but with all its advantages, it is cheaper than common barrow work when the excavation becomes deep, because then the plank track must be made so very long for procuring the necessary gradual slope, that it increases the number of sloping or short stages to such an extent as to be very expensive.

Stages.—Another mode of raising soil out of deep excavations, without a horse run, is by what is called *casting up by stages*. A scaffolding is formed with as many boarded platforms, at 5 feet above each other, as will reach the required height. They are placed one beyond the other, like the

steps of a stair-case, and a man with a shovel is placed on each. The lowest man, who digs the soil, throws it by his shovel on to the lowest stage, and the man stationed there delivers it, in like manner, on to the stage next above him, and so on in succession, until it reaches the surface. This method is sometimes resorted to, but is a very slow one, and not to be recommended.

225. *Slips* in earthworks, both excavations and embankments, and failures in retaining walls are in the great majority of instances attributable to defective drainage. This, therefore, is a point requiring the most particular attention. Arrangements must be made for allowing the water falling on the surface of earthworks to flow freely away, and every possible receptacle of drainage from the neighbourhood, or collection of water, however apparently insignificant, must be carefully looked to, and provision made for carrying the water off or preventing its accumulation. Water falling on the slopes should be received in what are called *catch-water drains*, at the foot of the bank; and, if necessary, higher up also on the slope (*see* figure); and these drains must be so directed as to carry the water away from the works. Spade cuts or channels passing obliquely from the summit of a slope to these drains, so as to form a repeated outline of the letter V on the face of the banks, are generally sufficient to complete the surface drainage.

Should the land slope towards the cutting, a catch-water drain is also necessary at the top of the slope, to exclude from the excavation, water draining off or flowing from it. These *catch-water drains* are usualy open ditches from 3 to 4 feet wide, and from 2 to 3 feet deep. In like manner, measures must be taken to prevent the admission of water to the back of revetment walls, or to ensure its free escape. The drains provided for the revetments of cuttings are sometimes united with those in the bottom of the excavation, sometimes carried off independently, as the nature of the works or form of the ground renders most convenient.

226. *Drains.*—For the drainage of roads and railroads in cuttings, the most economical and efficient method is the construction of open side drains, from 6 inches to 2 feet deep, receiving all the surface water and carrying

care has to be bestowed upon the work, for which a remuneration is always allowed. Thus, all removal of soil is paid for according to the distance it is carried, and if that distance should be increased by forming an embankment, instead of throwing the earth at the sides of the work as it proceeds, this would constitute a fair item of charge.

Again, should the earth be required to stand against water, as stated before, it should be laid in regular layers or strata, and rammed, or *punned*, in order to break the lumps and make the work more solid and compact; and this is an additional charge. The punning is performed by rammers of cast-iron* or wood hooped with iron to prevent their splitting, and worked by men; when adopted, the courses of earth should never exceed 9 inches in thickness, otherwise the blows of the rammer will have little or no effect on the under part of the stratum; and whether the operation of punning is performed or not, *it is impossible for the workmen to wheel* and deliver the soil on to an embankment with the same nicety and precision as to form, as can be obtained in excavating soil from the earth. All embankments, therefore, must be rugged and uneven when first formed, and they require what is called *trimming*, to reduce them to even and fair surfaces. The trimming consists of filling up hollows and cutting off protuberances, and this accordingly is charged separately, at a price agreed upon and regulated by the superficial measure of the surface of the embankment, instead of its solid contents. The same kind of trimming takes place upon the surface of all excavations, but it is never made a separate charge, being included in the price for doing the work and considered as a necessary finish to it.

237. Puddling.—If the excavation or embankment is intended to hold or retain water, another process called *Puddling*, may be requisite. Some natural soils are of a nature capable of holding water without any artificial assistance, and clay or loam are of this character; others again, as sand or gravel, and the *débris* of stony rocks, absorb all the water that may be deposited above them, or they permit it to percolate or run through them. This likewise is the case with almost all artificial embankments when first made, even though they may have been punned in their courses and every pains taken in their construction; and as it is a matter of great importance in the construction of navigable canals, that they should retain and hold all the water thrown into them, particularly where

* Cast-iron rammers, weighing 12 lbs. are supplied at the Roorkee Workshops at Rs 1-8 each.

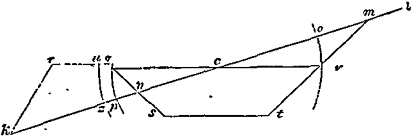
water is scarce, or their elevation is such that the escape of it might prove detrimental to the adjoining lands, and as no canal can be formed without raised embankments in some parts of it, so strict attention to the process of puddling, by which alone the escape of water can be prevented, is of the greatest importance.

No cheap and common material is found to oppose the filtration and passage of water so effectually as a soft loamy clay, when it is well worked or kneaded into a soft paste with water, and is not permitted to dry again. Even if a little fine gravel is mixed with the clay it seems to hold better, but this can only arise from the small stones assisting in the kneading process. The silt or natural deposit of tidal rivers is also an excellent material, but stiff or strong and plastic clay does not answer; or rather, it takes more time and labor to bring it to the proper consistency than can be afforded, as after it has been worked in a pug-mill, it forms an excellent material for stopping water. Puddling is nothing more than lining the bottom and banks of canals or reservoirs with this prepared clay or loam so as to enable them to hold water effectually, and the only difficulty is in the mode of doing so effectually.

238. The ordinary method resorted to in England for rendering ponds water-tight, after they have been formed in soil that will not hold water, is to line them to a thickness of from six inches to a foot, with clay beaten up with water and wheat or rye straw *(bhoosa)* by a hoe, and then to apply it as a plaster, as soon as it has become sufficiently dry to prevent its slipping or sliding down. It remains exposed to the air a few days, in order that the outer surface may become dry enough to maintain its form, and then the water should be let in upon it, so as to fill it, and if well executed, it will generally prove water-tight. It is, however, by no means a good or effectual process unless there is the certainty of the pond always remaining equally full, and of the water not being disturbed by cattle going into it to drink, or other causes. A perfect adhesion seldom takes place between the natural soil and this lining; consequently, if it is disturbed, it will gradually give way and subside to the bottom of the reservoir, thus leaving the old surface of the ground in contact with the water. If the height of water is subject to change, a considerable portion of the top of the lining becomes exposed to the sun, and in drying will crack and open through its whole thickness, thus permitting the water to escape when the pond becomes full again. This may be partly

prevented by covering the upper part of the lining with sods or turfs of grass, but as the grass will not grow and thrive under the water, it only affords protection to the upper part.

239. The only means, therefore of using a puddle lining effectually is to enclose it within the bank in such a manner that it is supported by earth on both sides, is kept constantly moist, is never exposed to the sun or external air, or indeed to disturbance of any kind, and then it will last, and be effective for ever; and such is the process that should constantly be resorted to in puddling the banks of canals. This is done by forming what is technically called a *puddle-gutter* in the bank, but the manner in which this must be made must depend upon the nature of the soil to be dealt with. Thus, suppose in the portion of canal represented in the



wood-cut that the soil bounded by the original surface line *kl*, should be clay or any earth that is capable of retaining water, there will be no necessity for pudding any part of the work, except the newly formed bank, *krqn*, which is wholly above the surface and may require securing. In this case as the natural soil is good, it will only be necessary to form a puddle within the bank, the transverse section of which is shown by the lines *uzqp*, and for this purpose an excavation must be made longitudinally in that bank like a foundation or opening for building a wall; and such an excavation is called a puddle-gutter. It must extend from the top of the bank down to the natural surface, and even penetrate at least a foot or 18 inches into it, and must be wide enough for a man to work conveniently in it, the usual width being from 30 inches to 3 feet.

All the previously contained soil having been thrown out, the process of puddling begins. This is performed in England by a man using a scoop-tool, like *Fig.* 2, page 241, and wearing a pair of very thick and strong boots made for the purpose, called puddling-boots. They come above the knee and should be impervious to water, like the high boots usually worn

As the cheeks of the mortise and the tenon are exposed to the same amount of strain in a system of framing, it follows that each should be equal to one-third of the thickness of the timbers in which they are made.

The length of the tenon should be equal to the depth of the mortise, so that its end should press home on the bottom of the mortise when its shoulders bear upon the cheeks; but as perfection in execution is unattainable, the tenon in practice is always made a very little shorter than the depth of the mortise, that its shoulders may come close.

When the mortise and tenon joint is cut, adjusted, and put together the pieces are united by a key or tree nail. The key is generally round, with a square head, and in diameter is about equal to a fourth part of the thickness of the tenon.

244. Angle Joints.—*Strut and Tie-joint*—The first case of the first mode of jointing above referred to is exemplified in *Plate* XXV., *Fig.* 1.—No. 1 shows the joint formed by the meeting of a principal rafter and tie-beam, *c* being the tenon. The cheeks of the mortise are cut down to the line *d f*, so that an abutment *e d* is formed of the whole width of the cheeks, in addition to that of the tenon; and the notch so formed is called a *joggle*. No. 2 shows the parts detached and in perspective. It will be seen that a much larger bearing surface is thus obtained.

Fig. 2.—No. 1 is an elevation of a joint, differing from the last by having the anterior part of the rafter truncated, and the shoulder of the tenon returned in front. It is represented in perspective in No. 2.

Fig. 3.—Nos. 1 and 2 show the geometrical elevation and perspective representation of an oblique joint, in which a double abutment or joggle is obtained. In all these joints, the abutment, as *d e*, *Fig.* 1, should be perpendicular to the line *d f*; and in execution, the joint should be a little free at *f*, in order that it may not be thrown out at *d* by the settling of the framing. The double abutment is a questionable advantage; it increases the difficulty of execution, and, of course, the evils resulting from bad fitting. It is properly allowable only where the angle of meeting of the timbers is very acute, and the bearing surfaces are consequently very long.

Fig. 4.—Nos. 1 and 2 show a means of obtaining resistance to sliding by inserting the piece *c* in notches formed in the rafter and the tie-beam: *d e* shows the mode of securing the joint by a bolt.

Fig. 5.—Nos. 1 and 2 show a very good form of joint, in which the

it off to the ends of the excavation. Care should be taken not to put these side drains too closely under the slope, otherwise they may cause the slope to slip, and they themselves may be crushed or choked by it. When economy of space is an object, and the width of the cutting cannot conveniently admit of these open side drains, they are dispensed with by employing instead, a central underground drain about $2\frac{1}{2}$ feet below the surface, with which branches communicate at intervals, conveying into it the surface drainage. The most frequent form of these central drains is cylindrical, and such are called *barrel drains*. They are also sometimes, when only required to be of small size, made of semi-cylindrical tiles; sometimes of stones laid as in *Fig*. 1. *Fig*. 2, represents the section of a barrel drain; *Fig*. 3, a section through one of the heads of the drain covered with an iron grating.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4 represents the section of a cutting having an open side drain for the excavation itself, and a central barrel drain for the reception of the surface water from the ground above and behind the revetment. *Fig*. 5 is the section of a railway cutting without side drains, the surface water being directed into the central drain by the *invert i*. If the water which has access to the back of a retaining wall cannot all be carried off by drains on the surface, it may be necessary to open communication between the earthwork, and the open cutting, by piercing the revetment; as shown in *Fig*. 6,

Fig. 4.

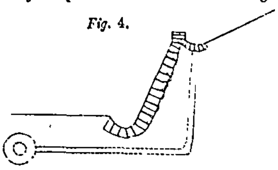


Fig. 5.

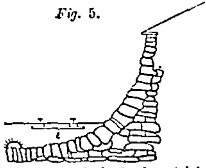
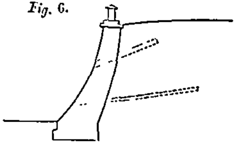


Fig. 6.



which is the section of retaining wall on the line of the London and Birmingham railway. The drains in this instance are iron pipes.

In order to keep hill roads free from water, and also to preserve their outer edges, it is recommended to give the surface a slight inclination towards the inner or hill side; along which will run the drain receiving both the surface water of the road, and that of the hill above. The water thus received is passed into covered masonry drains crossing underneath the road to the outer side, and is so carried off. These cross drains are constructed at intervals in convenient positions; larger ones being always built in the re-entering angles, which mark the courses of natural streams, themselves requiring an exit to the valley below.

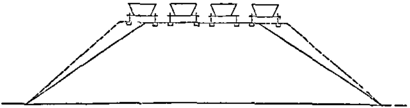
CHPATER XI.

EMBANKING AND PUDDLING.

227. The best materials for embankments are those whose frictional stability is the greatest and most permanent, such as shivers of rock. shingle, gravel, and clean sand. Wet clay, vegetable mould and mud, are evidently unfit for embankments.

Embankments may be made in three ways—1st, In one layer; 2nd, In two or more thick layers; 3rd, In a succession of thin layers. The first is the cheapest and quickest method, and is the one followed in most cases where there is no special reason to the contrary. The earth is raised at once to its full height, throwing it down from the commencement of the embankment; and, as the work proceeds, from the extremity of the completed portion. The objection to this method is, that, not having been rammed, the earth is subject to a greater amount of settlement, and after completion of the work, takes longer time to settle permanently than if formed in courses and rammed. A road or other work constructed on the surface of banks so formed, immediately after completion, will be liable accordingly to subsequent derangement and injury. There is not the same objection to the use of this method, when the earthworks are to be allowed to stand for a length of time before being used for their ultimate purpose. To accelerate the construction of an embankment, the top breadth is sometimes made greater than it is to be

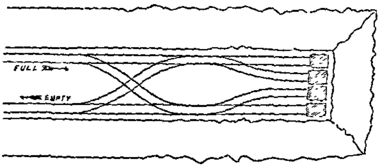
Fig. 1.



eventually, so that room is afforded for bringing forward a greater num-

ber of earth wagons. The bank is afterwards reduced to its proper form and dimensions, by cutting away the superfluous earth at the sides. Should a railway be employed, in such an instance as that represented in the figure, it is to be observed that there is no occasion to lay down four lines of rail in order to give four wagons abreast at the head of the embankment. Two lines only, are usually laid down, having each two termini, and what is called a double crossing, as represented in the figure, by means of which, four full wagons brought in train along one line, can, at the end, be all brought to the front, and return empty along the other

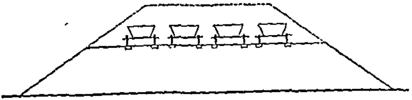
Fig. 2.



line of rail—as will be readily comprehended by reference to the figure. Where the embankment is not to be very broad, no tipping over the sides should be allowed; for the earth so tipped is liable afterwards to slip off.

228. The second method in use for forming embankment, (without the objections to which the above mode is liable,) is to make the bank of half the proposed height at first; the greater breadth of surface at the lower stage affording an enlarged space, admitting of the employment, in a similar manner to that described above, of a greater number of earth wagons than could be brought to the front at one time on the top of the embankment when of the full height.) The layer is then

Fig. 3.

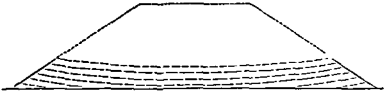


left for some time to settle before commencing another. This system

involves much additional time and labor, and is seldom employed. It is, however, useful in making embankments of hard clay or shale, which consist at first of angular lumps which do not form a compact mass until partially softened and broken down by the action of the air.

229. The third mode is to be preferred as ensuring the greatest density and stability, though more slow and expensive than either of the above, namely laying down the earth in successive layers, from 6 to 12 inches in thickness, each being well rammed before the next is laid down. It is recommended to make these layers concave, this construction having been found to contribute greatly to the prevention of slips in new embankments.

Fig. 4.



This being a tedious and laborious process is used only in special cases, such as the filling in behind retaining walls, and in making sides of canals, or embankments for tanks, for which purposes it should always be adopted.

230. When the height of an embankment is greater than 15 feet, it has been recommended to make it in two portions, one on each side of the ground to be covered; leaving a valley in the middle; this being afterwards filled in, will be prevented, by the first raised embankments, from spreading unnecessarily, thus causing an earlier solidification of the mass, and a smaller expenditure of material carried and of ground occupied.

Somewhat on this principle was the great embankment for the Solani Aqueduct at Roorkee formed. Trenches were first dug to the right and left of the line 188 feet by $5\frac{1}{4}$ feet deep, (*Fig.* 1, *Plate* XXIV.,) and the earth from them was thrown on the centre so as to form a nucleus for the raised embankment which was to constitute the bed of the canal. The earth was so thrown as not to interfere with the building of the two side revetments. On the central embankment thus raised, a railway was laid on which trucks plied, and as it progressed, lateral flanks *aa*, (*Fig.* 2,)

were raised to a level with the railroad for carrying the earth to the embankments in rear of the revetments, or as far back as the line, *bb* (*Fig.* 3). These side roads, *aa*, occurred at intervals of 200 feet, and hollows were thus left between them which acted as reservoirs for receiving rain water. By this means moisture was distributed by absorption and the whole banks settled and became consolidated. In this manner the work went on for five years, when the holes were filled in and the whole embankment was completed up to the level of the railroad. The two side banks were then raised to their full height, the earth being carried in trucks as stated in the last Chapter, and the work was completed. The outside slopes were $1\frac{1}{2}$ to 1, and the upper surface of the embankments outside the revetments was 30 feet broad.

231. In adjusting with precision the dimensions of earthworks, with a view to the exact equalization of excavations and embankments, it must be borne in mind that earth formed into an embankment, being compressed by ramming in the course of construction, occupies less space than before excavation. The following Table shows the result of the comparative measurements of some works of this kind in different descriptions of soil :—

Nature of soil.	Amount of excavation.	Contents of embankment	Compression.	
			Actual.	Proportional
	cubic yards.	cubic yards.	cubic yards.	
Clayey soil, ...	6,970	6,262	708	0·1015
Another do., ...	25,975	23,571	2,404	0·0925
Light sandy soil, ...	10,701	9,317	1,384	0·1293
On the whole, ...	43,646	39,150	4,496	0·1030

the total compression amounting to above one-tenth of the earth excavated. Gravelly earth was found to be compressed about 1-12th. Rock, on the other hand, can never in embankment be made to assume so small a bulk as before excavation.

All *made earth* is liable to *settle*, that is, the surface to sink, and the whole volume to contract, after completion of the work. The amount of settlement depends on the nature of the soil the height of the work, and the method in which it was formed. It will be less if the earth has been well rammed; and, in works of different dimensions, all other circumstances being alike, it has been found to vary nearly as the cube of the height.

SOLANI EMBANKMENT.

Fig I

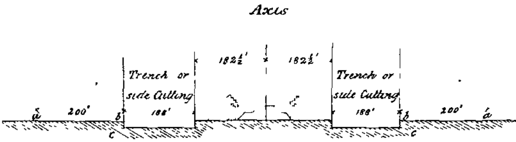


Fig 2.

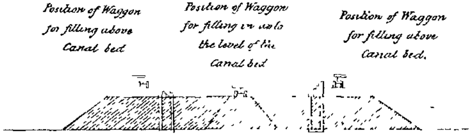
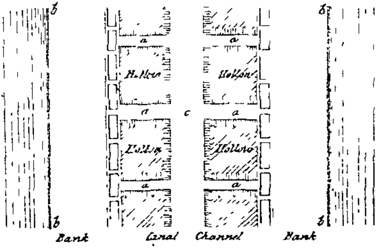


Fig 3



by adopting a very shallow slope when working in soil that appears to threaten their occurrence, and carefully providing drains or gutters on the top of the work, with sufficient fall to carry the water away rapidly, or before it has time to settle into the new work. A catch-water drain will also be necessary along the foot of an embankment if there is any danger of water draining off to the adjoining lands and sapping the foundation of the work.

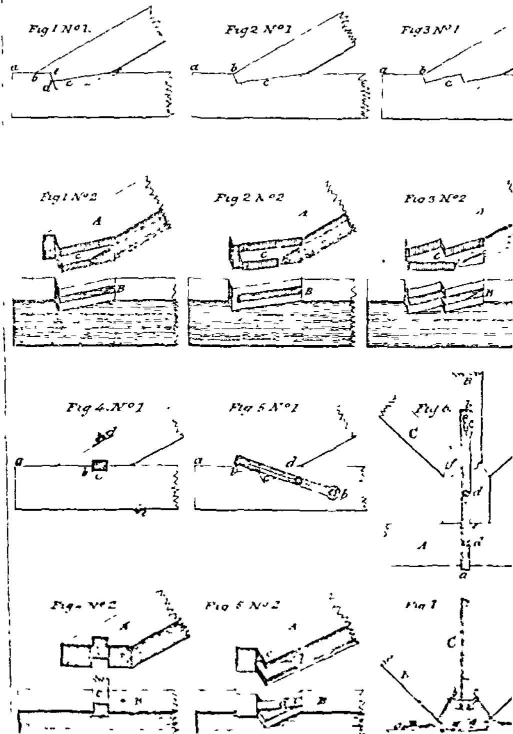
When the natural ground has a steep sidelong slope, it is in general necessary to cut its surface into steps before making the embankment, in order that the latter may not slip down the slope. The best position for these steps is to make their surfaces at right angles to the direction of the pressure of the earth upon them. They should, at any rate, incline to the horizon, if anything, in an opposite direction to the slope of the natural ground.

235. When the earth is so soft that an embankment made in the ordinary way would sink in it, different expedients are employed according to the degree of difficulty to be overcome. It may be sufficient to dig side drains parallel to the site of the intended work, and so, by carrying off all the water, consolidate the ground lying between them. Sometimes it may be advisable to dig out the soft ground, and make a regular foundation of stable material on which the embankment will stand. Or, if the soft ground has, at no very great distance beneath the surface, a firm substratum, a foundation of stones or gravel may be laid going right down to this basis. Sometimes the earth is compressed and consolidated by driving short piles into it

In the celebrated example of Chatmoss, which was from 10 to 31 feet deep, containing nearly double its bulk of water, George Stephenson formed a secure foundation for heavy railway traffic at a cost below the average of the other parts of the line in the following manner:—Drains were cut about every 5 yards apart, and when the moss between them was quite dry it was used for the embankment. On this were laid hurdles either in single or double layers; and over them the ballast. By thorough draining in this way, cuttings as deep as 9 feet, and embankments as high as 12 feet, were formed in a quagmire in which an iron rod would sink with its own weight.

236. Notwithstanding an embankment may in many cases be formed without expense, still it generally happens that some additional labor or

JOINTS AND STRAPS.



place of the mortise is supplied by a groove c in the rafter, and the place of the tenon by a tongue (or *bridle*) d in the tie-beam. As the parts can be all seen, they can be more accurately fitted, which is an advantage in heavy work. In No. 1 the mode of securing the joint by a strap $b\,b'$ and and bolts is shown.

In making each of these joints, care must be taken that the length of the fibres left between the abutment at b and the end a of the tie-beam, is sufficient to resist safely the tendency of the longitudinal component of the thrust against the abutment or notch to shear them off: that is to say,

let H = horizontal component of thrust of rafter.
b = breadth (in inches) of tie-beam.
l = distance (in inches) from notch to end of tie-beam.
f = resistance of wood to shearing.
s = a factor of safety.

Then

$$H = lb\frac{f}{s}, \text{ or } l = \frac{s\,H}{b\,f}$$

According to Tregold, 4 is a sufficient value for s in this case: and if we take for the value of f in the case of oak 2,300 lbs, or for fir, 600 lbs.; the value of l would be, for oak $\frac{H}{575\,b}$, for fir $\frac{H}{150\,b}$.

If the rafter and tie be bound together with a bolt or strap, in a direction making as acute an angle as practicable with the tie, the joint is made much more secure.

245. *King-post joints.*—*Fig.* 6 shows the several joints which occur in framing the king-post into the tie-beam, and the struts into the king-post. A is the tie-beam; B the king-post; and C and D, struts. The joint at the bottom of the king-post has merely a short tenon e let into a mortise in the tie-beam. The abutment of the strut D is made square to the back of the strut, as far as the width of the king-post admits, and a short tenon f is inserted into a mortise in the king-post. The abutment of the joint of C is formed as nearly square to the strut as possible.

The term *king-post*, gives quite an erroneous notion of its functions, which are those of a suspension tie. Hence the necessity for the long strap $b\,a$ bolted at $d\,d$, and secured by wedges at c. The old name *king-piece* is better than king-post.

Fig. 7.—In this figure, the superior construction is shown, in which a king-bolt of iron CD is substituted for the king-post. On the tie-beam

A, is bolted by the bolts *a e, d f*, the cast-iron plate and sockets *a b c d*, the inner parts of which *h g, h g*, form solid abutments to the ends of the struts BB. The king-bolt passes through a hole in the middle of the cast-iron socket-plate, and is secured below by the nut D. A bottom-plate *e f* prevents the crushing of the fibres by the bolts.

Plate XXVI.—*Figs.* 1 to 5 show various methods of framing the head of the rafters and king-posts by the aid of straps and bolts.

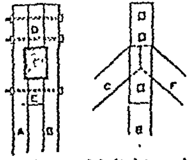
Fig. 6 shows at D what may be considered the upper part of the same king-bolt as is shown in *Plate* XXV., *Fig.* 7, with the mode of connecting the rafters. A cast-iron socket-piece C receives the tenons *a a* of the rafters AA, and has a hole through it for the bolt, the head of which *b*, is countersunk. B is the ridge-piece set in a shallow groove in the iron socket-piece. An elevation of the side is given, in which G is the bolt, F the socket-piece, and E the ridge-piece.

Figs. 7, 8, 9 and 10, illustrate the mode of framing together the principal rafter, queen-post, and straining-piece. In the first three examples, the joints are secured by straps and bolts; and in the last example, the queen-bolt D passes through a cast-iron socket-piece C, which receives the ends of the straining-piece and rafter, as those of the two rafters are received in *Fig.* 6.

Figs. 11 and 12 show modes of securing the junction of the collar-beam and rafter by straps; and *Figs.* 13 and 14, modes of securing the junction of the strut and the rafter by straps.

In all these cases where the strut and rafter abuts against a notch or shoulder abutment in the king-piece, the distance of the notch or shoulder from the end of the piece is to be determined by the same formula as in the case of a rafter abutting on the end of a tie-beam.

246. A better mode, however, than any shown in *Plates* XXV. and XXVI., where the framing admits of the arrangement is to make suspending pieces in pairs, so that the rafters from which they hang may abut between them directly against each other. C and F are the ends of a pair of rafters abutting against each other. A and B, the upper ends of a pair of suspending pieces, notched upon



the rafters, and bolted to each other through the blocks, or filling pieces,

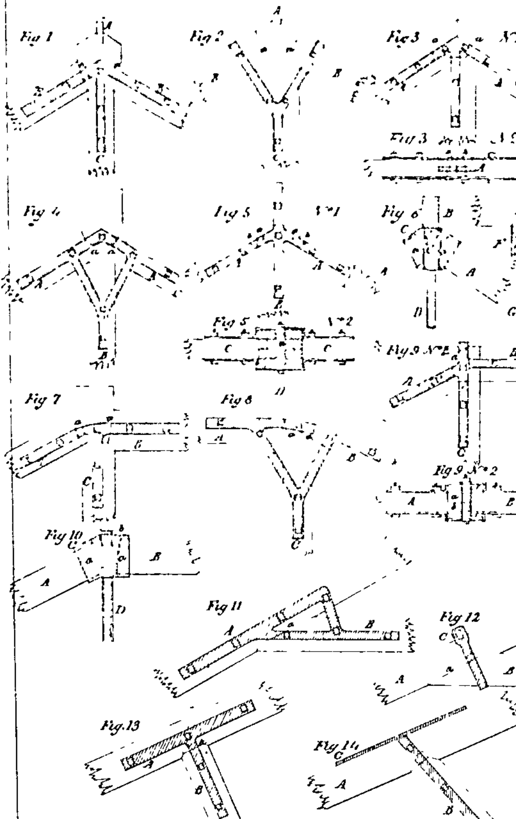
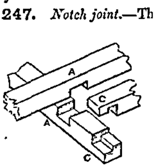


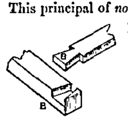
Fig 1
Fig 2
Fig 3
Fig 3
Fig 4
Fig 5
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 9
Fig 10
Fig 11
Fig 12
Fig.13
Fig 14

D and E. If these figures be turned upside down, they will represent the lower ends of a pair of suspending pieces, forming a wooden stirrup for the support of a beam, or of the ends of a pair of struts, as the case may be.

247. *Notch joint.*—The third case of the first mode specified in para. 242, is applicable to *wall plates*, and timbers in similar positions. If one timber altogether crosses, or slightly overlaps the other, the joint may be of the form shown at A, when the beams are said to be *halved*: but in a case when the ends have to be cut fair, (as in *external* wall-plates,) the arrangement shown at C, should be adopted.



This principal of *notching* with square abutting joints should invariably be abopted in preference to *dove-tail* joints (as at B), which owing to internal shrinking of the wood cannot be depended on in Carpentry (though admissable in some kinds of Joinery).



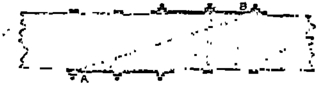
248. Lengthening Timbers.—The second and third modes of joining, specified in para. 242, which are applicable to beams, posts, &c., joined in the direction of their length, are termed *scarfing* and *fishing*, and are performed in a variety of ways dependent upon whether the lengthened timber is to be subjected to compression, tension, or cross strain.

Scarfing.—Where two pieces of timber are joined so as to preserve the same breadth and depth throughout, and thus to appear like one piece (as in most neatly finished work) *scarfing* is adopted. In each part of the timber to be joined, the parts of the joints which come in contact (as at AB, *Fig.* 1) are called *Scarfs*; and if the scarf be formed with an indented surface, its projections are termed tables (as at *ac*, *c'b*, *Fig.* 3). In forming a scarf it should be borne in mind that—(1) the bearing parts should have as large a bearing surface as possible; (2), this surface should have the best form for resisting the strains to which it will be subjected; (3), the effect of the inevitable shrinkage and expansion should be considered; (4), the timber should be cut as little as possible; and (5), all unnecessary complications and difficulties in workmanship should be avoided.

The case of beams subject to *tensile* strain will be first considered. It is

obvious that if a simple oblique scarf be made at the end of each beam, and the two scarfs AB, BA, be brought into over-lapping contact, the joint AB is useless as regards connection of the scarfed pieces, until secured by bolts. Iron plates or *straps* are interposed between the nuts and timber, to prevent the fibres of the latter being crushed by the screwing up of the nuts. Here the distance from A to B is called the length of the scarf: and the strength depends entirely upon the bolts and straps.

Fig. 1.

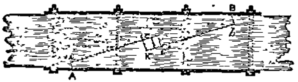


If, however a *key* or pair of wedges of hard wood be added in the middle of the joint, notched equally into both beams, the key and indents in the scarf will furnish *some* resistance to the opening of the joint under tensile strain: but not sufficient to obviate the necessity for bolts.

Fig. 2.

This form of joint is very much improved by each scarf being *tabled* and indented, the key being interposed (as in the second case), between the *table a c* of the lower, and the table *b c'* of the upper scarf. In this case a continuous strap of iron is placed both above and below the joint to prevent injury from the bolts, and the ends of the strap may be slightly bent and let into the wood. The key or double wedge K should only be driven so as to bring the parts to their proper bearing: as it would be better to omit it than to drive it so as to produce much constant strain on the joint. When bolts are to be added, before their insertion the joints should be brought to a bearing by means of the key.

Fig. 3.

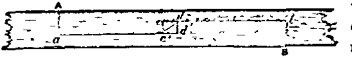


The *oblique* scarf, as shown above, has little to recommend it beyond the facility of construction and capability of being easily fitted. Bolts (if

introduced) do not press the surface in a perpendicular direction, and the oblique pressure must have some tendency to separate the joint.

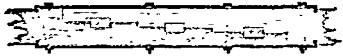
The form of scarf shown in *Fig.* 4 involves no difficulties in carpentry, and has the advantage of square abutments Aa, Bb, $c'c$, dd', and no oblique surfaces. This scarf would answer without bolts: but its strength would be much increased by the addition of straps and bolts (as in No. 3), and in this case the key is necessary.

Fig. 4.



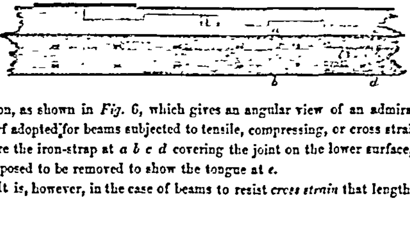
Scarfs are often made with numerous tables, indents and keys: but the multiplication of their details increases the difficulties of workman-ship and the chances of inaccurate fitting. No. 5, is however a form of scarf given by Tredgold, and specified as very simple and easy to execute; it is a modification of No. 4.

Fig. 5.



In the case of beams and joints subjected to *compression*, it is evident that oblique scarfs and abutments are altogether inapplicable. Such joints however as are adapted for beams subjected to tensile strains, and have side abutments truly perpendicular to the direction of the force, are equally suited for compressed posts and beams. To prevent side shifting it is advantageous to add at the end of each scarf a *tongue* or mortise and

Fig 6.



tenon, as shown in *Fig.* 6, which gives an angular view of an admirable scarf adopted for beams subjected to tensile, compressing, or cross strains. Here the iron-strap at $a\ b\ c\ d$ covering the joint on the lower surface, is supposed to be removed to show the tongue at e.

It is, however, in the case of beams to resist *cross strain* that lengthen-

obvious that if a simple oblique scarf be made at the end of each beam, and the two scarfs AB, BA, be brought into over-lapping contact, the joint

Fig. 1.

AB is useless as regards connection of the scarfed pieces, until secured by bolts. Iron plates or *straps* are interposed between the nuts and timber, to prevent the fibres of the latter being crushed by the screwing up of the nuts. Here the distance from A to B is called the length of the scarf: and the strength depends entirely upon the bolts and straps.

If, however a *key* or pair of wedges of hard wood be added in the middle of the joint, notched equally into both beams, the key and indents in

Fig. 2.

the scarf will furnish *some* resistance to the opening of the joint under tensile strain: but not sufficient to obviate the necessity for bolts.

This form of joint is very much improved by each scarf being *tabled* and indented, the key being interposed (as in the second case), between

Fig. 3.

the *table a c* of the lower, and the table *b c'* of the upper scarf. In this case a continuous strap of iron is placed both above and below the joint to prevent injury from the bolts, and the ends of the strap may be slightly bent and let into the wood. The key or double wedge K should only be driven so as to bring the parts to their proper bearing: as it would be better to omit it than to drive it so as to produce much constant strain on the joint. When bolts are to be added, before their insertion the joints should be brought to a bearing by means of the key.

The *oblique* scarf, as shown above, has little to recommend it beyond the facility of construction and capability of being easily fitted. Bolts (if

introduced) do not press the surface in a perpendicular direction, and the oblique pressure must have some tendency to separate the joint.

The form of scarf shown in *Fig.* 4 involves no difficulties in carpentry, and has the advantage of square abutments Aa, Bb, $c'c$, dd', and no oblique surfaces. This scarf would answer without bolts: but its strength would be much increased by the addition of straps and bolts (as in No. 3), and in this case the key is necessary.

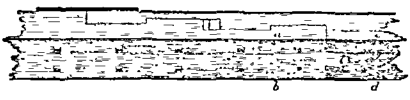
Fig. 4.

Scarfs are often made with numerous tables, indents and keys: but the multiplication of their details increases the difficulties of workman-ship and the chances of inaccurate fitting. No. 5, is however a form of scarf given by Tredgold, and specified as very simple and easy to execute; it is a modification of No. 4.

Fig. 5.

In the case of beams and joints subjected to *compression*, it is evident that oblique scarfs and abutments are altogether inapplicable. Such joints however as are adapted for beams subjected to tensile strains, and have side abutments truly perpendicular to the direction of the force, are equally suited for compressed posts and beams. To prevent side shifting it is advantageous to add at the end of each scarf a *tongue* or mortise and

Fig. 6.

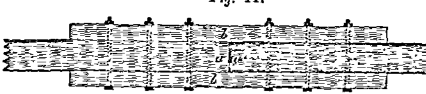


tenon, as shown in *Fig.* 6, which gives an angular view of an admirable scarf adopted for beams subjected to tensile, *compressing*, *or cross* strains. Here the iron-strap at $a\ b\ c\ d$ covering the joint on the lower surface, is supposed to be removed to show the tongue at e.

It is, however, in the case of beams to resist *cross strain* that lengthen-

abutting the two ends (*a*, *a*, *Fig.* 11) together, placing a piece of timber

Fig. 11.



(*b b*) on each side, and firmly bolting these together. It is obvious that in a *tie* the strength of this joint depends on the bolts, and the lateral adhesion and friction produced by screwing the parts tightly together: the timber is weakened only so far as its effective sectional area is diminished by the bolt holes.

The dependence on the bolts may be lessened by indenting the parts

Fig. 12.

together as shown by the upper side of *Fig.* 12; or by putting keys in the joints as shown by the lower side of the same figure; but the strength of the beam will be decreased in proportion to the depth of the indents.

The only reasons for not wholly depending on the bolts are, that should the parts shrink ever so little, the bolts lose a great part of their effect, and the smallness of the bolts renders them liable to press into the timber and then to suffer the joints to yield.

The sum of the area of the bolts should never be less than one-fifth the area of the section of the beam, and they should not be placed too near the ends of the pieces.

In the case of a strut or post under compression, the two pieces should abut against each other at a plane surface, perpendicular to the direction of the thrust; and to keep them steady they may either be fished on all four sides, or have their abutting ends enclosed in an iron socket made to fit them. Joints in struts should if possible be stayed laterally.

250. Trussed Girders.—When the bearing exceeds about 22 feet, it is very difficult to obtain timber large enough for girders; in such cases it is usual to truss them.

considered by many practical men to be nearly useless. The beam is considered to be crippled before the iron begins to be strained, and therefore this mode of trussing is not now in much favor.

Fig. 4.—Nos. 1 and 2 illustrate the application of the tension-rod on what may be considered the queen-post principle, there being two stirrups at *a a*.

Fig. 5.—Nos. 1 and 2 show a combination of timber and wrought-iron. The beam is composed of three flitches, the two outer being of timber, and the central of boiler-plate. The flitches are bolted together. In the elevation it is the iron flitch that is shown.

251. Built beams.—Another way of obtaining timbers, for large spans, is by building beams so as to increase their depth. In *Fig.* 1, *Plate* XXVIII, two pieces of timber are built into one beam of double the depth of either, by the aid of hard-wood *keys* or *joggles*, (which resist the shearing stress at the surface of junction,) and of vertical bolts in the spaces between the keys. It is obvious that no key nor bolt should be put at the middle of the span; because in general there is no shearing stress there; and also because the bending moment is in general a maximum there, and it is desirable to weaken the cross-section as little as possible. The grain of the keys should run vertically. According to Tredgold, the aggregate depth of all the keys should amount to *once and a-third*, the total depth of the beam, and the breadth of each key should be twice its depth. Rankine suggests that the keys should, as in *Fig.* 2, make an angle of 45° with the surface of the beam, a plan as yet untried.

In *Fig.* 3, the two pieces of which the beam is built are indented into each other, a sacrifice of depth being thus incurred equal to the depth of an indent. The abutting surfaces of the indents face outwards in the upper piece, and inwards in the lower, so as to resist the tendency to slide. According to experiments by Duhamel, the aggregate depth of the indents should amount to *two-thirds* of total depth of the beam. The beam in the figure is slightly tapered from the middle towards the ends, in order that the hoops which are used to bind it may be put on at the ends and driven tight with a mallet.

When a beam is built of several pieces in length as well as in depth, they should break joint with each other. The lower layer should be scarfed or fished like a tie, and the upper should have plain butt joints.

The upper layer of a built beam is sometimes made of hard-wood, and the

BUILT BEAMS

Fig 1

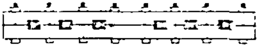


Fig 2

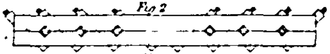


Fig 3.

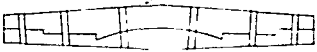


Fig 4

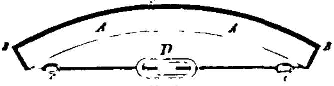


Fig 5

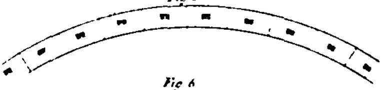


Fig 6

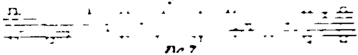


Fig 7

Fig 8

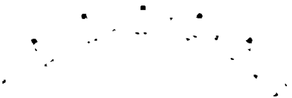


Fig 9

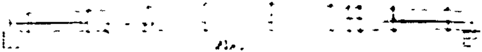
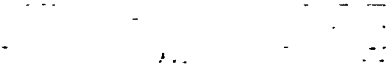


Fig.



259. A great disadvantage of the flat roof is that water runs off slowly, and if the upper coating or terrace has cracked from the great heat in the dry season, (which is frequently the case,) leakage occurs during the rains. To give the roof a slight inclination and thus assist the flow of water, the beams should be so cut as to have a rise in the middle. This, which is called a *camber*, should be effected not by bending the beam upwards, but by shaping it; for if the former is done, the beam on settling has a tendency to thrust out the walls. This slope also should never be given by increasing the thickness of terrace, as by this the girder is weighted at the very point where it is least able to bear it. A good method, however, is to cut the beam even and screw on wedge-shaped pieces of wood in the middle or top of the beam to give the necessary fall towards the two ends.

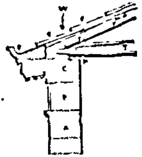
260. **Pent or Trussed Roof.**—This roof with a covering of thatch, tiles, slates, or iron, is adapted to all spans, and is the most economical and suitable form where timber is used.

By various arrangements of the timbers in the construction of the framing, and by artifices in bending and building beams, such as described in the preceding Chapter, great breadths of building can be covered. In one instance, (that of the Riding School at St. Petersburg,) a span of 235 feet was successfully roofed with timber; but for such large spans iron is now, when procurable, always substituted for wood. The two kinds of pent-roof in common use are the *gabled* and *hipped*. In the former, the roof is formed by the intersection of two planes which slope upwards from the wall plates on the sides of the building, meeting at an angle at the ridge, the walls at the end being built up vertically to the ridge, and finished off to the same angle. In the latter, the roof is formed of planes which slope up from both the sides and the ends of the building to the ridge, the wall plates being on the same level all round. Both are common in India.

261. The *Pitch of a roof*, or the angle which it makes with the horizon, varies in different countries and climates, and even in the same country the pitch has varied considerably at different times according to the fancy of the builders. Formerly in England, roofs were made very high; but these, though having some advantage in countries where snow falls, expose a large surface to the wind, and therefore would, in a country like India where storms are sometimes very violent, be out of place. In high pitched roofs, too, the coverings are apt to slide, while on the other hand

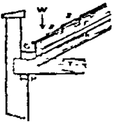
in very low pitched roofs, the wind will get under the tiles and remove them, and the strain on the walls, (as will be seen further on,) is very great. A moderate pitch is therefore generally adopted, and the height of a roof either in England or India for buildings in general, now rarely exceeds one-third of the span, or is less than one-sixth. For tiles or slates about one-fourth the span or 27°, and for thatch 35°, is the usual pitch; though the latter may be as great as 45°, or half the span.

262. To exclude wet from the inner surface of the walls and allow the roof drainage to pass freely away, the surface of the roof covering should be advanced well beyond the supporting walls, as in the annexed wood-cut illustrating the section of an old Greek roof. Here ABC represent



the architrave, frieze and cornice: the latter projecting far beyond the wall, and carrying the *epititheas* (E) or stone gutter, which by its position and form prevented any overflow from wetting the timbers. Here also the junction of the rafter R with the tie-beam T of the roof truss occurs over the centre of the supporting wall, and brings the thrust more directly over its supports. The long tiles *t*, *t*, are carried on purlins *r*, *r*, resting evenly on the principal rafter.

In many modern English houses the principal rafter R abuts on the tie-beam T and concentrates the roof thrust on a



point *within* the wall: and the roof drainage is collected in a lead gutter G, which when overflowing, leaks within the building, and over the most important roof timbers: the free flow of the drainage being stopped by a parapet wall which rests on the ends of the trusses. This latter arrangement should be avoided.

263. King-post Truss.—*Plate* XXIX., *Fig.* 1, is a pent roof, adapted for spans not exceeding 30 feet. The combination of beams in a roof is called a *truss*—the figure represents *a King-post truss*. The component parts of it are as follows:—

1. *Wall plates.*—Pieces of timber laid on the wall in order to distribute the pressure of the roof over a large bearing surface. These may also be of stone (*vide* P P of preceding wood-cuts.)

2. *Rafters.*—Two pieces of timber forming the inclined sides of the truss, supporting the purlins. (B, B, of *Fig.* 1, *Plate* XXIX.)

3. *Tie-beam.*—A horizontal piece of timber connected to two opposite rafters, its main object being to tie down their ends and thus prevent the walls from being thrust outwards. It is also useful as a support for ceilings and punkahs. (A.)

4. *Purlins.*—Horizontal pieces of timber notched on the rafters, and at right angles to them, extending from truss to truss. On these is laid the roof covering. (*b*, *b*.)

5. *King-post.*—An upright piece of timber in the middle of a truss, framed at the upper end into the rafters, and at the lower end into the tie-beam. This prevents the tie-beam from sinking or *sagging* in the middle. (K.)

6. *Struts.*—Oblique straining pieces framed below into the king-posts, and above into the rafters, which they help to support. (E, E.)

In English trusses, the rafters above described are more precisely termed *principal* rafters; common or *secondary* rafters are sometimes laid on them outside the purlins, to carry the roof covering.

264. Queen-post Truss.—*Fig.* 2 shows a roof truss called a *Queen-post Truss*, the two verticals on either side being the *queen-posts*. This is adapted for spans of from 30 to 45 feet. The timber between the upper ends of these two is the *straining beam* (C); that between the lower ends, the *straining sill* (*h*). The other timbers are the same as in the former truss.

The following would be the scantlings in fir of the several timbers of such a truss (at 10 feet intervals, for a weight of 66½ lbs. per square foot, according to Tredgold:—

A, Tie-beam, ...	12 × 6	inches.
B, Principal rafter, ...	10 × 6	,,
C, Straining beam, ...	9 × 6	,,
D, Queen-post, ...	8 × 6	,,
E, Strut, ...	6 × 6	,,
F, Common rafter, ...	6 × 2½	,,
a, Pole-plate, ...	9 × 6	,,
b, Purlin, ...	12 × 9	,,

265. *Fig.* 3 is adapted for spans up to 60 feet. It is often necessary to build trusses of greater span, but the general principle is that shown here.

Fig 2

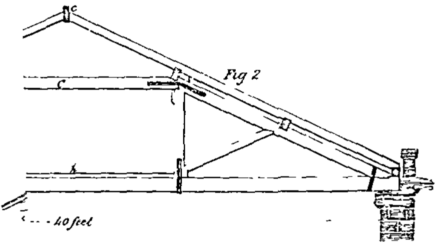
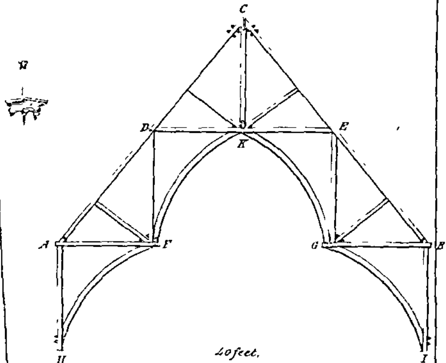


Fig 5



Scale, 12 feet = One inch

The following would be the scantlings for the above weight of roofing, by Tredgold's rules, under the same conditions as above:—

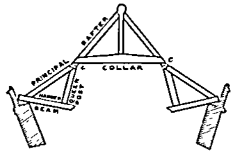
Principal rafters,	...	...	...	... 11 × 6	inches.
Tie-beam, ...	...	...	...	... 12½ × 6	"
Queen-post B,	...	...	...	... 8 × 6	"
Suspending post A,	...	...	...	... 3½ × 3	"
Struts (large),	...	...	...	... 4½ × 3½	"
" (small),	...	...	...	... 3½ × 2½	"

266. *Fig.* 4.—A roof adapted to a hall or church with nave and aisles. The framing is simple and good:—

A, Principal tie.
B, Tie of aisle roof.
C, Girder supported by the iron column D.
D, Story-post.

267. Hammer-beam Truss.—*Fig.* 5 shows a high roof suitable for a Church or Gothic building.

In this roof AC, BC, are principal rafters: DE is a *collar beam* which tying the rafters together, not at their feet, but at considerably higher points, does not counteract any tendency of these rafters to bend between D, A, and E, B, and to thrust out the walls. The curved tension pieces KF, KG, are consequently introduced to tie the ends of the *hammer-beams* AF, BG to the centre of the collar beam; curved struts HF, IG, being also introduced to aid in keeping the ends F and G in position. Without the curved struts and tension pieces as shown in *Fig.* 5, and strongly built or buttressed walls, a lofty and heavy roof carried on collar and hammer-beam trusses, would be likely to fail as in the annexed wood-cut.



268. In trussed roofs, especially those of large spans, a combination of iron and wood may often be substituted for wood alone. Such trusses are much lighter and look much better; the only difficulty is in properly connecting those parts where the iron and wood meet together.

Plate XXX., *Fig* 6, shows a truss for a roof of 44 feet 8 inches span. In this, wrought-iron is used for the suspension rods, and cast-iron shoes as abutments for the timbers acting as struts.

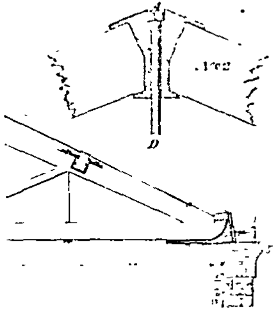
On the wall-head, is a cast-iron shoe, to receive the tie-beam and the foot of the principal rafter. The sole-plate of the shoe is prolonged, to admit of its being secured by bolts to the tie-beam.

The head of the principal rafter, is inserted into a cast-iron socket, an elevation of which is seen, enlarged at No. 1. The suspension rod AD, it will be seen passes through the solid part of the socket. It has a head at its upper end, and at its lower end it is screwed, and secured by a nut. To avoid cutting the principal rafters, the purlin at B is also carried in cast-iron rests bolted to the rafter. The centre suspending rod at E, passes through a socket, which serves as an abutment to the struts. Similar abutments are provided for the struts.

Fig. 7.—This truss is for a roof of 45 feet span. The detail No. 2 is a section of the shoe at head of king-bolt, into which the upper ends of the principals are inserted.

269. *Fig.* 8 represents a truss of 40 feet span, constructed by Colonel Waddington at Bombay, supporting, with other trusses placed at intervals of 10 feet, a roof which slopes 30° from the horizon, and has an extreme span, from cave to eave, of 50 feet. The tie-beam is supported at equal intervals of 8 feet, and the purlins and wall-plate are also separated by equal distances of 6·35 feet. The struts, rods, and queen posts are so disposed as in a great measure to neutralize pressure on the principal rafters, except in direction of their length; and the common rafters are supposed to extend in one length from ridge to eave, and to be 15 inches apart. The battens are each 2 × $\frac{3}{8}$ inches, and their edges 2 inches apart, covered by a double bamboo mat; the eaves single-tied, the lower row being laid in chunam, the rest of the roof double-tied, and the ridge of chunam.

270. *Fig.* 9.—The roof covering of the Central Hall of the Allahabad Passenger Station is 78 feet long by 38½ clear by 27 feet high. The trusses are of sál, and are 11 feet apart from centre to centre, each truss *carrying a permanent load of 18 tons 3 cwt., not including its own weight.* The straining piece or girder is composed of two solid pieces of timber scarfed in the centre. The curved portion is made of pieces 12 by 5 inches, bolted together, making the cross section 12 by 10 inches. The pieces break joint with one another, the centre of one piece acting as a tie to the abutting ends of the other pieces to which it is bolted. The covering of the roof consists of sandstone flags, 4½ inches thick, placed on



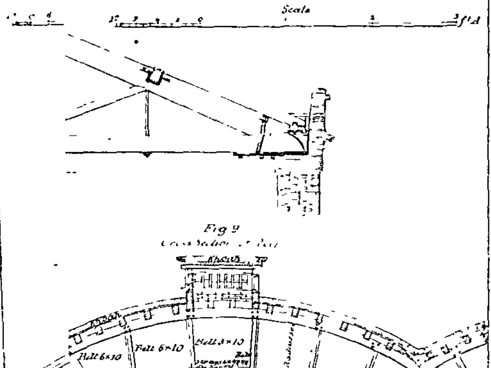


Fig 9

purlins 2 feet apart; above the flags, the *Lhoa*, (broken bricks and mortar,) 6 inches thick, is placed in the usual way.

271. The roof, although the last part of a building which is constructed, is one of the first to be considered in preparing a design; for on its weight the thickness and nature of the walls depend. In the case of flat roofs, both the construction and calculation are very simple; indeed little or no carpentry is necessary for the first, and as all the timbers are subjected to a direct transverse strain, their strength and proportions are easily determined. But in a trussed roof the nature and effect of the strains to the timbers are various; and in their connection, the best form of joint and fastening has to be considered, so that they may preserve the form of truss desired with as little change as possible.

272. SCANTLINGS.—The investigations of the stresses on the various pieces forming a roof, and the formulæ expressive of the scantlings proper to varying loads are discussed in the section on Strength of Materials.

273. EXPLANATION OF TABLES.—The accompanying Tables of Scantlings of sál timbers (the wood in principal use in Northern India) for Wooden Roofs have been reprinted (with slight alteration of notation to suit the new Section V. on "Strength of Materials") from the last edition of this Treatise.

They may although calculated as for sál timber be made available (sufficiently accurately for practical purposes) also for other timbers by taking the scantlings calculated for larger spans in sál wood, thus:—

(1). For Teak, take the scantlings corresponding to a span 1 foot wider.

(2). For Deodar, " " 2 "

N.B.—There are *two important differences* between the method of calculation originally adopted (and now reprinted) for these Tables, and that recommended in this Edition, *see* Art. 2, (2), and Art. 6, (2—iv.), of Section V., "Strength of Materials."

(1). The rafters were designed to bear *only the greater* of the two straining actions, (*i. e.*, Direct and Transverse,) to which they were exposed, *see* Art. 2, (2) (of Section V.)

(2). The effect of wind was estimated according to Tredgold's rule as a "*uniform vertical load of* 40 lbs. *per square foot over the whole roof;*" this method was formerly the accepted rule of the profession, and has still high authority in its favor, *see* Art. 6, Part (2—iv.), (of Section V.)

There is also a minor difference between these Tables, and the method adopted in the text, *see* Art. 16 and 21 (of Section V.), viz., that the weights w' w'' in the Text *of this Edition* were both included in the w *of the Tables*, but although theoretically correct to separate them *as in this Edition*, it has not been thought

worth while to recalculate the Tables on this account, as the alteration in the scantlings would be very trifling.

Table, No. VI., has been calculated to admit of a comparison being made of the increase required in the scantlings in Table, No. IV., supposing the trusses to be placed at 10 feet apart, instead of at 7 feet, as calculated for in the latter Table. By comparing these two Tables it will be seen that, so far as the scantlings of the rafters are concerned, the results given in Table No. VI. are equivalent to an increase in Table No. IV., of about two places for the smaller spans, and of from three to four places for the larger spans.

The differences are much greater for the scantlings of the tie-beam, strut, and king-post; but as these are always made greater in practice than they are found by calculation, it will be sufficient, for all practical purposes, to take the scantlings of the rafters as a guide in making the comparison for any particular case.

The only exception to this, appears to be in the case of an iron tie-rod being substituted for the tie-beam, in which the increase shown in Table, No. VI., is equivalent to about seven places in Table, No. IV.

It will be understood from the above remarks, how Table No. IV., may be made available for determining the scantlings of the several pieces of a truss, supposing the trusses to be at 10 feet apart.

The trusses to be at 7 feet apart, the purlins at 3 feet apart, and the battens
on to roof covering, effects of rain, wind, &c. The truss is supposed to be of

safety* (s) has been taken as 10.

…l area of king-post $= \frac{K}{1150}$		Breadth of rafter† $= b = \sqrt[4]{\frac{l^2}{4} \times \frac{W}{4} \cos 23^\circ \times \frac{25\sqrt{2}}{4 \times 4963}}$		Depth of rafter $= d = b\sqrt{2}$.		Least sectional area of iron rod that may be substituted for the tie-beam ‡
…ion.	Practically, might be made, say.	By calculation.	Practically, might be made, say.	By calculation.	Practically, might be made, say.	
	inches.	inches.	inches.	inches.	inches.	inches.
	3⅛ × 3⅛	3·124	3⅛	4·418	4½	·899
	3¼ „ 3¼	3·294	3¼	4·659	4⅝	·965
	3½ „ 3½	3·455	3½	4·830	4⅞	1·013
	3⅝ „ 3⅝	3·580	3⅝	5·062	5⅛	1·081
	3¾ „ 3¾	3·695	3¾	5·226	5¼	1·133
	3⅞ „ 3⅞	3·862	3⅞	5·461	5½	1·203
	4 „ 4	3·974	4	5·619	5⅝	1·252
	4⅛ „ 4	4·132	4⅛	5·843	5⅞	1·321
	4¼ „ 4	4·245	4¼	6·003	6	1·370
	4⅜ „ 4	4·399	4⅜	6·221	6¼	1·440
	4½ „ 4	4·507	4½	6·374	6⅜	1·491
	4⅝ „ 4	4·655	4⅝	6·583	6⅝	1·557
	4¾ „ 4¼	4·769	4¾	6·745	6¾	1·614
	4⅞ „ 4¼	4·919	4⅞	6·956	7	1·682
	5 „ 4¼	5·027	5	7·109	7⅛	1·740

…s; and the ridge pole about 4 × 5¼ inches. If the purlin be made square in
slight increase would be required, were any of the weaker kinds of wood to

CHAPTER XIV.

CENTRES.

274. A *Centre* is a timber frame for supporting the stones or bricks of an arch during its construction. Its qualities consist in its being sufficiently strong and stiff to bear the whole pressure of the arch stones, during the building of the arch, from its springing to its keying. It should be capable of being easily romoved, and as it is only a temporary frame, should be so made, if possible, that its timbers may be of further use. In narrow streams where intermediate supports can easily be established, this framing should always be made upon horizontal tie-beams, supported in several places by piles sunk in the bed of the river; in such cases, then, the construction of a centre is comparatively easy; but, in navigable rivers where it is difficult to place such supports, where space must be left for the passage of vessels, and where there is danger from floods, the construction of a centre requires much skill. In large arches, where the arch stones rise to a considerable height, they often force the centre out of form by causing it to rise at its crown; to prevent which, it is sometimes necessary to load the centre, but this is a make-shift, and would not be necessary if the centre were well constructed. In making centres, it is not enough to consider what weight they will bear without fracture, but what they will bear without derangement, as, upon this quality of stiffness and preservation of form, depends the goodness of the arch.

Centres are composed of several vertical frames or trusses, connected by horizontal ties and stiffened by braces. In cases where they span the whole width of the archway, the off-sets of the stone-work afford a substantial abutment for their support. The frames or trusses of the centres are usually from 4 to 6 feet apart, one being placed under each of the outer rings, and the others dividing the intermediate space; from truss to

truss, horizontal timbers extend, called *laggings*, and these support the arch stones.

275. Pressure on Centres.—Before proceeding to lay down any rule as to the construction of centres, it will be necessary to show how to find the pressures of the different arch stones on them.

It is usually stated that arch stones do not begin to press against the centre, until courses are laid, the slope of whose beds is steeper than the angle of repose; that is to say, from 25° to 35°, or about 32° is the average: but in order that this may be true, the lower part of the arch must be so thick as to have no tendency to *upset inwards;* a thickness equal to about one-tenth of the radius of curvature of the intrados is in general sufficient for that purpose, but still any accidental disturbance of the arch stones may make them press against the centre.

Each successive course of arch stones that is laid, causes the pressure exerted by the previous courses against the centre to diminish, and when a semi-circular arch is completed, all but the keystone, the stones whose beds slope less steeply than 30°, have ceased to press against the centre, even though there should be no friction; in fact, when the load on the centre reaches its greatest amount, its action is nearly the same whether friction operates sensibly or not; and remembering this, and also that the calculations caused by neglecting friction err on the side of safety, it appears, that for practical purposes, it is sufficient to calculate the load, as if the friction between the stones was insensible.

If μ be the co-efficient of friction (represented by $\tan\alpha$, when α is the angle of repose), and β be the inclination of the lower joint of a stone to the horizon, W the weight of an arch stone, and P the pressure.

$$\text{Then } P = W(\sin\beta - \mu\cos\beta).$$

The following is a table of co-efficients at various angles, the difference of two successive joints being 2°.

Angle of inclin.	34°, P = ·04 W	Angle of inclin.	48°, P = ·33 W
"	36°, P = ·08 W	"	50°, P = ·37 W
"	38°, P = ·12 W	"	52°, P = ·40 W
"	40°, P = ·17 W	"	54°, P = ·44 W
"	42°, P = ·21 W	"	56°, P = ·48 W
"	44°, P = ·25 W	"	58°, P = ·52 W
"	46°, P = ·29 W	"	60°, P = ·54 W

This Table might be extended, but when the plane of the joint becomes

so much inclined, that the vertical through the centre of gravity of the arch stone does not fall within its lower bed, the whole weight of the arch stone should be considered as bearing on the centre.

276. *As an example.*—To find the pressure of the arch stones upon 22° of the centering, counting from the joint which makes 32° with the horizon. Sum the preceding Table from 32° to 54°, and multiply by the weight of a portion of the arch stones comprehended between 2°, the product will be the pressure required.

Thus, suppose the frames of a centre to be 5 feet from middle point to middle point, the depths of the arch stones to be 4 feet and the space comprehended in 2° measured at the middle of the depth of the stone, to be 1·5 feet. Then the solid content will be 30 cubic feet, and taking 150 lbs. as the specific gravity of stone, the weight will be 4,500 lbs. This sum multiplied by the sum of the preceding Table, 2·70, gives 12,150 lbs. for the pressure required.

From an inspection of the table, it will be seen that the pressure increases very slowly until the joint makes a considerable angle with the horizon. For instance, at an inclination of 44°, the pressure is one-fourth the weight, at 58° more than a half, and near the crown, the stones rest wholly on the centre. In designing centres, therefore, this must be borne in mind, for it would be absurd to make them equally strong at every point. When the depth of the arch stone is double its thickness, the whole of its weight may be considered to rest on the centre, when the inclination of the joint is 60°. If the length of the stone is less than twice the thickness, it will rest on the centre when the angle is less than 60°, and if more than twice the thickness, the angle will be more than 60° before it does so.

When the arch stones are small, the pressure is a greater proportion of the whole weight than when they are large.

277. Framing of Centres.—For large spans in India, the centering most in use is formed by building a wall, or row of pillars, of brick in mud, in contact with the pier or abutment, and two or more parallel rows of pillars in the space between; wall or pillar plates are then placed over these transversely. On these are put strong rafters of rough wood, connected together by others forming the lagging, on which is built a mass of brick in clay; leaving the upper surface plastered with clay, and brought to the exact shape of the intrados of the arch; a little sand is

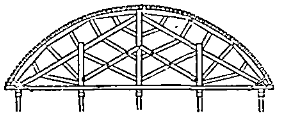
then sprinkled over it, and after being left for a day or two to dry, it is ready to build upon. Care must be taken that the timber is strong enough not to bend under its load. When the span is not very considerable, and (in the case of a river) there is no risk of flood, there is no objection to this kind of centre, as it is easily constructed and is economical; nearly all the bricks in the pillars, &c., as they are only set in clay, can be used afterwards to complete the bridge.

When however the span is more than 30 feet, it will be advisable to adopt a centering, composed of four or five timber frames constructed upon horizontal tie-beams supported in several places by brick pillars, from the top of which struts should radiate to support the main ribs in as many points as may be requisite. These main ribs are to be preserved from lateral movement by cross struts and braces, and the irregular polygon formed by them must be brought to the form required for the arch, by supplementary frame-work of slighter construction, under the lagging.

In important works these centering frames should be scientifically designed as "*trusses;*" and where intermediate supports cannot be used, it is imperatively necessary to construct trussed frames on the principles explained in the next paragraph.

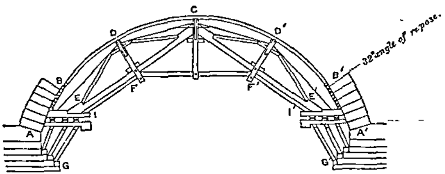
278. That a centre may be sufficiently strong to support any part or the whole of the pressure, and be stiff enough to do so without changing its form, the strains must not act very obliquely on the supporting pieces, the magnitude of the parts must be proprotional to the strains on them, and the component timbers be so disposed so as to prevent any part rising, instead of causing it to rise as is too commonly the case. *Fig.* 1 shows the centre designed by Smeaton for the Coldstream Bridge, and it is an admirable specimen of a centre where intermediate supports can be obtained; but when intermediate supports are impossible, more care is necessary in forming a design. It is obvious that laying a load on the haunches, must have a tendency to raise the crown, unless it be so constructed, that this tendency is counteracted. Let the line ACA′, *Fig.* 2, represent the curve of an arch, and let the arch stones begin to press upon the centre

Fig. 1.



at B, B′, where the joints incline at 32° to the horizon, and let the laying of the arch stones proceed alike on each side. Now if two trussed frames EDH, E′D′H′ abut against each other at C, the point cannot rise in a sensible degree from the pressures at D, D′, and much additional security may be gained by aiding the pieces FF′ with the pieces FI, F′I′. The framing of this centre begins on each side, nearly at the point where the

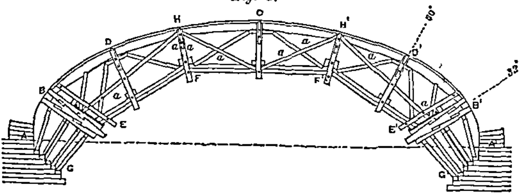
Fig. 2.



arch stones first exert pressure. The curved rib must be strong enough to bear the parts between BD and DC, but the bearings may be shortened by making the abutting blocks at D, D′, longer. The beams EC, E′C will be ties until the arch stones are laid beyond D, D′. They will then begin to act as struts, and will continue so to act until the whole arch is laid. This plan of centre will not do for a very large span, because it then requires a very long piece of timber, and the points of support for the curved rib become too far apart to be supported by timbers of the usual dimensions.

For a larger arch let EF, FF′, and F′E′, *Fig.* 3, be beams; let them be

Fig. 3.



trussed and abut against each other at F and F′. Then, it is obvious that when the loads press equally at D, D′, they will have no tendency to raise

the beam FF′ in the middle, unless it is too weak to resist the pressure in the direction of its length, and as it is easy to give any degree of strength that may be required, a centre of this form with little variation in the trusses, may be applied to any span which will admit of a stone bridge. When timber is not to be had of sufficient length, the beams EF, FF′ E′F′ may be built beams: according to the methods described in Chapter XII.

279. *Fig.* 1, *Plate* XXXI., shows a centre for a small span. It consists of a trussed frame, of which A is the tie, B the principal, or, as its outer edge is curved to the contour of the arch, it is called by Smeaton the *felloe*, C the post or puncheon, and F a strut. The centre is carried by the piles D, on the top of which is a capping piece E, extending across the opening; and the wedge blocks *a* are interposed, betwixt it and the tie-beam.

Fig. 2, another centre, also for small spans.

In *Fig.* 3, the weight of the centre of the arch is carried directly by the struts to the ends of the tie-beam; the tie-beam, struts, and king-post A making a simple king-post truss. Two other trusses support the arch above the haunches, and have a collar-piece between them at half the height of the arch. The ends of the cross-braces are seen at *a*

Fig. 4 shows a centre with intermediate supports and simple framing, consisting of two trusses formed on the puncheons, over the intermediate supports, as king-posts, and subsidiary trusses for the haunches, with struts from their centres parallel to the main struts.

280. *Indian Examples of Centering.*—In the annexed Plates are shown some other centres that have been used in different parts of India.

Plate XXXII. and XXXIII. Centerings used for the Ganges Canal Bridges.

Plate XXXII., *Fig* 5. Span, 20 feet, the ribs, ten in number (placed 4 feet apart), were supported on temporary pedestals made of brick and mud, erected close upon the piers The ribs rested on a striking apparatus consisting of the usual double wedge or pyramidal shaped bolts, which were supported by the above pedestals.

Fig. 6. The whole of the 55 feet span arches in the Northern Division, of the Ganges Canal, were built with this species of centering; its great merit consists in its being made with the kurrie or staple rafter brought from the Sewalik forests, in the kurries not being pierced or injured by tenon and mortise; and, consequently, by their being available for other pur-

poses afterwards. The design is an excellent and a most economical one.

Plate XXXIII., *Fig.* 7. Span, 55 feet, used for some of the bridges near Roorkee.

Fig. 8. Span, 50 feet, used at the Solani aqueduct.

Plate XXXIV., *Figs.* 9 and 10. Centerings with intermediate supports used in Madras.

Plate XXXV., *Fig.* 11. Captain Best's centering consists of a series of ribs, each composed of three planks, of which the upper one is horizontal, and notched at each end into two planks placed transversely; to which the other two planks, forming the rib are also notched at their upper ends, and have their lower ends resting on wedges, placed on a temporary brick-in-mud wall, pointed with chunam, in contact with the pier or abutment. Planks are laid over the ribs at right angles to support the usual stuffing of brick and mud. The ribs are placed about 2 feet apart, and planks 1 foot deep and $2\frac{1}{2}$ inches broad (if of good teak) will do for spans under 45 feet. If they are of mango or other inferior wood, the dimensions must be increased a little.

The advantages of this centering consist in the simplicity of its construction and the ease with which it may be carried from place to place, and as the planks, of which it is formed, are but little cut up in being prepared for the centering, they may be disposed of, if not required for another bridge, at nearly their original value.

Plate XXXVI., *Fig.* 12, shows the details of the centering used for the Wurda bridge of 7 arches of 50 feet span, and 10 feet rise. Three sets of centres were used, 5 ribs to each set; each rib weighing about $1\frac{1}{2}$ tons. This centering answered admirably, and was struck by means of sand cylinders as described in a succeeding paragraph.

281. Striking Centres.—When the arch is finished, the temporary supports have to be removed, and for this purpose several methods are used, which have to be provided for in the design and construction of the centering.

Wedges.—The most usual way, until sand-cylinders were introduced, was by means of wedges placed under the wall or pillar plates, by the striking of which on their sharp ends, the wall plates may be gradually lowered. These being double, it is evident that if their small ends, *aa*, are struck inwards, the line *ab* will be lowered, and with it the wall or pillar plate *c*, and anything supported by it.

CENTRES.

Fig 1

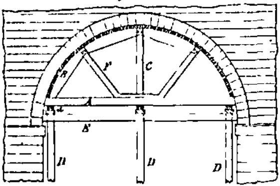


Fig 4

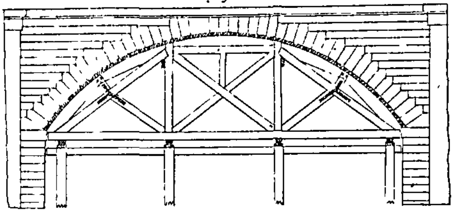


Fig 3

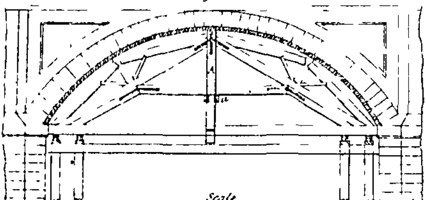
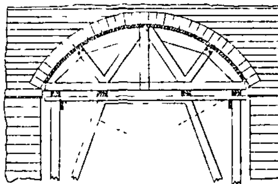


Fig 2.



GANGES CANAL CENTRES.

Fig 5

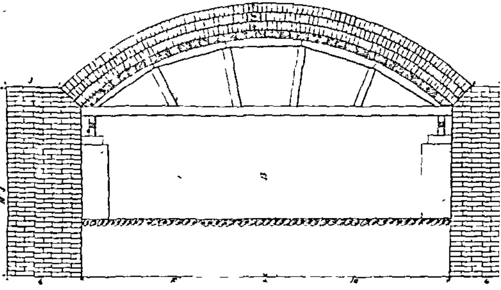
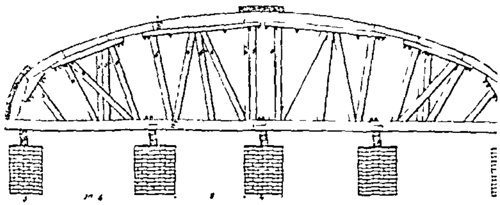
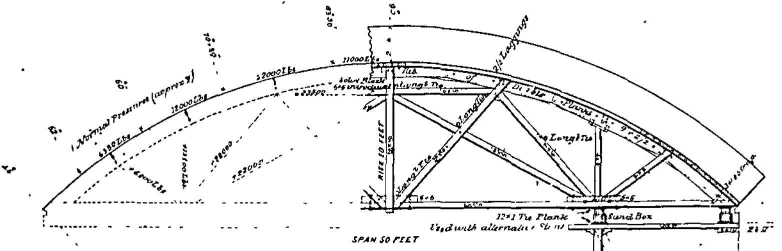


Fig 6



WURDA BRIDGE CENTRES.



TIMBER TEAKWOOD,	c. ft. in one platform under sand boxes	80
	" in one Truss or Rib, ...	50
	" Laggings and Tie planks per r. f. of bridge, .	12

Ribs or Frames 5′ 6″ apart from centre to centre.

Bolts through Rib planks only, 6″ long	$\frac{1}{2}$″ diameter	
" " as well as braces	8″ × $\frac{3}{4}$″	
" Tie beam " "	9″ × $\frac{3}{4}$″	
" " scarf,	11″ × $\frac{3}{4}$″	
Plates under scarf, .	36″ × 3″ × $\frac{1}{2}$″	
Pounds of Iron per Rib, . "	196	

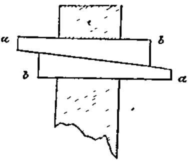
Length of ... of Arch ... 32
Wt of C F 190 Lbs

Rad = 36 2 ft

Scale = 8 ft to 1 inch

NOTE.—Middle stirrup and side diagonal Braces of 9″ × 2$\frac{1}{2}$″ might with advantage and at no extra cost be made of double

Wedges should be in sets of three; the middle one directly under the weight supported, the other two at equal distances on each side of it; then by striking the centre one first, the weight will be equally supported by the two side wedges, the centre one being refixed loosely, the side wedges may be struck till the weight is again borne by the middle wedge, and thus the lowering may be safely and gradually effected.



The wedges over every pillar should all be struck equally and simultaneously, but as this is difficult of accomplishment, it may be sufficient if the wedges are struck in succession, lowering slightly those in the centre line first, then those in the two next lines, and so on to those at the springing, taking care that the lowering is very gradual and equable.

282. In order to avoid the necessity for sending men in under the arch to strike the centerings, the wedges may be connected together on beams, so placed as to pass outwards from the two centre frames or trusses to either end of the arch; striking each beam inwards, lowers every centre frame resting upon it. In centerings entirely supported at the springing of the arches, four such beams, or two on each side, only will be required. In centerings on pillars, two will be required on each row of pillars, between the pillar plates and the trusses. In small arches these beams may be driven inwards with mallets, but in large arches the work may be done by a beam mounted and worked as a battering ram.

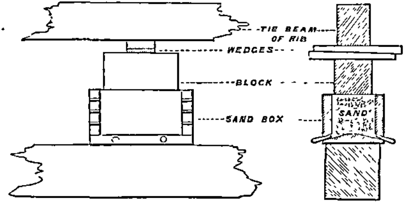
The wedges should be made of hard wood, and the beam above should also be hard and smooth; if a rough timber is placed on the top of a badly formed wedge, there will be the greatest difficulty in getting the latter to move at all; they should be thoroughly cleared of dirt and rubbish, and be well oiled before the process of lowering commences.

283. *Jack-screws.*—A still more gradual method of lowering centerings was used in constructing the Roorkee aqueduct, viz., by the introduction of jack screws in the place of the wedges, prior to lowering; this was effected by the use of triple wedges, the middle wedge being struck out without affecting the centering; its place being then supplied by the screw tightened up to receive the strain, the outer wedges were then struck away and the pressure left on the screw. The screw being well oiled and fully up to the work required of it, could be turned by means of

cone opposite each hole, and stops. When everything is ready, the Engineer gives the order to lower from 2½ to 2 inches; then, by means of the iron rods, the men remove the cones of sand, and help its escape with the curved end in the event of its having got wet during the progress of the work, until the piston shall have descended the distance required, which will be noted by a scale attached to each piston. The workman then allows the little cone of sand to accumulate and waits for a fresh signal, and in this way the centre descends gradually, and detaches itself uniformly from the arch, without shaking it. It will be seen that being completely master of the operation, leisure is given to make all necessary observations, so as to be assured that all goes on well, or to take measures should the contrary be the case. At the Pont d'Austerlitz, commenced the 20th May, 1854, and opened for traffic on the 8th November, the centres were struck in two hours, and it might have been performed in still less time by placing a man to each of the cylinders, so as to lower all the centres simultaneously. Each arch of the bridge was supported by 36 principals, and the enormous weight of both the masonry of the arch and the metal of the roadway, bore on the centres, they not having been removed until after the opening of the bridge to the public."

285. *Sand-boxes.*—This method has been lately much adopted in India, and the following are examples of its application in particular instances:—

E. I. Railway Bridges.—" Many of the bridges in the Mirzapore district are built with ashlar arches of 60 feet span and of great weight, necessitating a very strong centering; this consisted generally of seven ribs of sál timber, carrying for laggins a layer of the sleepers, afterwards used in the permanent way. The ribs were kept vertical by being tied together with cross braces, and were supported with four pairs of wedges under each rib in the usual way.



"The centering of our first arch was struck in the old way; a man with a sledge-

hammer was placed over each pair of wedges, and at a given word they all struck together. From that moment, the noise of the hammers rendered any further order inaudible, and the wedges came out one after the other, in no particular order according to their tightness or the strength of the hitting. The result was most unfortunate; the heavy ribs came down singly, and in so doing broke from the cross ties, and ultimately fell over on their side severely injuring some of the hammermen.

"It was this accident which caused the adoption of sand boxes, which were made in the following way :—

The box is made of 2-inch sál plank, 18″ × 9″ × 9″ inside dimension; the sides are dove-tailed into the ends, and the joints all secured with 5-inch screws; the top is left open. Over this box and resting on the sand, is a rectangular block measuring 16″ × 8″ × 8″, so as to give half an inch play at each side and one inch at the ends. At each side of the bottom of the box, are a couple of 1-inch holes sloping upwards and inwards, and closed for the time with wooden plugs loosely driven in and luted round with a little moist clay.

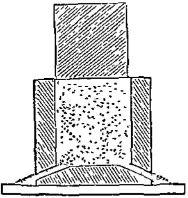
"When the arch is ready for striking, four of these boxes (28 in all) are placed under each rib as near as possible to the supporting wedges, the box filled with dry sand, the block laid carefully on the sand so as to be clear of the inner edges of the box, and a pair of greased wedges with only 1-inch taper are driven with a hand hammer between the block and the tie-beam of the rib. The old wedges are then easily knocked out, and the arch rests on the sand and is freed by drawing out the plugs.

"The same set of boxes was used for sixteen arches without receiving any material damage.

"This construction of sand-boxes may perhaps appear too simple to be worth describing, and the only feature to which I wish to draw attention is, that the surface of the sand is left uncovered for half an inch all round the edges and shows no tendency to overflow, notwithstanding the enormous weight laid on it, it being the property of sand not to transmit lateral pressure beyond a certain angle.

"The central surface of sand on which the block is laid forms such an unyielding bed, that in transferring the weight of the arch and centering from the old wedges to the sand boxes, the greatest subsidence observed at the crown was never more than one-eighth of an inch.

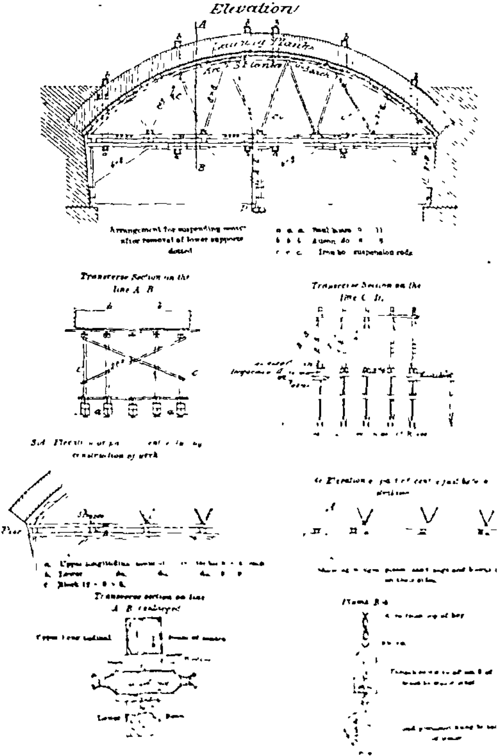
"The play thus allowed to the block is essential to its steady descent, because as the sand is let out by the sides, its upper surface does not remain horizontal, and the block being no longer on a level bed, would, if made to fit tight, most inevitably get jammed and stop or burst the box; any close fitting plug or piston will I think be found to fail on this account.



"I would suggest the following modification of the above construction as applicable to very large spans, or to any case where the arch requires *to be let down slowly*, or the process of lowering to be stopped at any point.

"Dispense with the plugs, and let the box stand on a plank a foot wider than itself so as to form a shelf 6 inches wide under the plug holes; thus the sand from the holes will stand on this plank in small cones at about 30° to the horizon, and will stop the

MORHUR BRIDGE CENTRE.



CHAPTER XV.

FLOORS, PARTITIONS AND STAIRCASES.

287. ALTHOUGH double-storied houses are rare in India, more especially up-country, still they are occasionally built, as in the case of new Barracks, houses in the hills, &c. We shall therefore describe Timber Floors, Partitions, and Staircases, which are generally required when the building consists of more than a single story.

Floors.—Tredgold describes three sorts of floors—*single joisted, double joisted*, and *framed*. These are respectively shown in *Figs.* 1, 2, 3, of *Plate* XXXVIII. It was found by experiment that the single joisted floor was the strongest; indeed, the complication of the others is quite unnecessary as regards strength, and results only from a desire to make as perfect a ceiling as possible, it being found that ceilings so supported are little subject to cracks and irregularities; in India, where ceilings are not considered essential, the single joisted floor should undoubtedly be used. As planking is generally difficult to obtain, and is apt to warp or rot, the floor of an upper story is often made with tiles, and plastered in much the same way as a flat roof, the girders and burgahs disposed in the same way as in its construction, and the calculation for them being of a precisely similar nature; but, as a floor should not oscillate by the movement of people, it is better to have frequent timbers of a *stiff section*, than infrequent timbers of a section which is *stronger*, but not so *stiff*.

288. *Plate* XXXVIII., *Fig.* 1.—*Bridging joist or Single joisted Floors.*—No. 1 is the plan of an apartment: *a a a a*, are the walls, *b b* the wall-plates, *c c c c*, &c., the bridging-joists, *d d* part of the flooring boards. The bridging-joists are usually placed from 10 to 12 inches apart: their scantling is dependent on their length, their distance apart, and the weight they have to carry, and may be calculated as in the case of flat roofs.

No. 2 shows a section through the joists at right angles to their direction: *c c* are the bridging-joists, *d* the edge of one of the flooring-

boards, *e e* the side of a ceiling-joist. The ceiling-joists cross the bridging-joists at right angles, as seen at *e e e*, No. 1, and are notched up to them and fastened with nails. Sometimes every third or fourth bridging-joist is made deeper than its fellows, and the ceiling-joists are then fixed to them only. This has the advantages of preventing sound passing so readily, and making the ceiling stand better.

289. When the bearing of single joists exceeds 8 feet, they should be strutted between, to prevent their twisting, and to give them stiffness. When the bearing exceeds 12 feet, two rows of struts are necessary; and so on, adding a row of struts for every increase of 4 feet in the bearing.

There are three modes of strutting employed, the first and most simple is to insert a piece of board, nearly of the depth of the joists, between every two joists, so as to form a continuous line across. The struts should fit rather tightly, and are simply nailed to keep them in position. The second mode is to mortise a line of stout pieces into the joists in a continuous line across, but the mortises materially weaken the joists. The third mode is represented in the section No. 2; *f f* are double struts, of pieces from 3 to 4 inches wide and $1\frac{1}{4}$ inch thick, crossing each other, and nailed at the crossing to each other and at their ends to the joists. The struts should be cut at their ends to the bevel proper for their inclination. To save the trouble of boring holes for the nails, two slight cuts are made at each end with a wide-set saw, and the strut is nailed through these with clasp-nails. Of the three modes, the last is the best. In No. 1, *f f f* show three lines of struts.

290. *Trimmers.*—When some joists would, from their position, run into a fireplace or flues in a wall, it is improper to give them a bearing there. In the case of the floor, *Fig.* 1, two short timbers, called "trimmers," are introduced—one on each side of the place to be cleared, with one end resting in the wall, and the other framed into the third joist from it: into the outer side of these, respectively, the end portions of the two first joists are framed, the intermediate portion being dispensed with. The joist into which the trimmers are framed is called the "trimming-joist," and is made thicker than the others, according to the number of joists dependent on it for support. The hearth rests on a brick arch turned between the trimmer and the wall. Trimming is also resorted to for stair and other openings.

291. Timber partitions are internal vertical divisions used in

the upper stories of a building, to make the separations required in forming the apartments. When such apartments are more numerous than in the lower stories, the partitions should be so constructed as in no way to influence, by their weight, the integrity of the ceilings of the rooms beneath; and their weight therefore should be transferred, by the system of framing, to the immovable points of the structure.

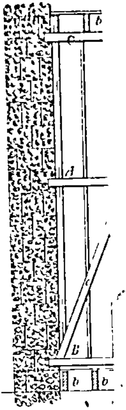
To accomplish this, trussed or quartered partitions are used. These are framed on the same principle as a king or queen-post roof; and are equally capable of bearing a strain proportionate to the scantling of the timbers of which they are composed.

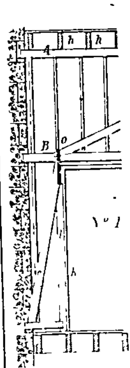
Timber partitions should not be used in dividing the ground floors into apartments, because of their liability to be affected by damp. Stones or bricks are the proper materials to use in such places.

292. *Plate* XXXIX., *Fig.* 1, is a partition trussed on the principle of the queen-post roof. The object aimed at in this case is to resolve all the pressures or weights of the partition into vertical or downward pressure on the walls, which in the example before us, is rendered easy by the symmetrical arrangement of the openings. For it will be readily seen that the pieces DD, with the intertie AA, the straining-piece *h*, and the struts *d* acting in the same manner as roof principals, form a queen-post truss; the intertie AA being rendered continuous as a tie-beam by the straps at *a a*. The strut *c* serves to discharge the downward pressure at *m* to the wall; and the counter-strut *f* the pressure at *n* to the foot of the queen-post D. The actual stability of the partition, however, depends on the upper trussing; that is, on the framing composed of the tie AA, the posts DD, the principals *d d*, and the straining-piece *h*. C is the headpiece of the partition, B its sill, *l* the door-posts, and *i i* the door-frame; *b b*, *b b* are the joists of the floors above and below. The counterbraces, such as *g*, prevent the sagging of the main struts, and give additional stiffness and firmness to the framing.

This partition is at right angles to the direction of the joists *b b*, and therefore when the door-posts do not fall upon a joist, it is necessary to support them by pieces, as *k*.

293. *Fig.* 2, No. 1.—In this example, the intertie B, the post D, and the struts *g*, form a king-post truss. The door-posts *l*, are secured by the straps at *o* and *p*, the intertie is continuous, and the king-post is





rendered so by the strap at *m*. The sill is sustained by the strap at *n*, and thus the whole system of the framing is dependent on the upper portion of the truss: *e* and *f* are the struts, and *kk* the doorcase; A the headpiece, and *hh* joists of the floor above.

In No. 2, the upper portion of the truss is on the queen-post principle D is the intertie, which, as before, is the tie-beam; *e* is the strut forming the principal, and *f* the straining-piece. The door-posts A, B, are suspended by the straps *c c*, E is the sill, *d* a strut or brace, *g* a counterbrace, and C the headpiece.

294. Joiners' work.—Doors. The door and door frames are two distinct parts of the *house-fitting*. The door frame consists essentially of four pieces, called stanchions or posts, and a topsill or lintel and a groundsill. For external doors, the parts are generally of solid timber cut with a rebate on the inner faces for the door to shut against; the topsill or lintel is almost always of solid timber, as even if it has no superincumbent weight to carry, (which it should not have,) the stability of the door depends much on the bonding of the topsill into the wall. The groundsill is generally of hard wood or stone, in order to withstand the wear of the traffic. The framing together of these four pieces is done in the manner of ordinary carpenters' framing, and the timber is generally wrought or planed. It is fixed in the reveal constructed in the wall to keep the wind and rain from passing between the frame and the wall; hence an external door always opens inwards, an arrangement suitable both for convenience and defence. The frame of an internal door may be made in the same manner as that of an external door, and set in a reveal in the wall; but it is usual in ordinary houses to line the whole of the door opening in the wall with wood for the sake of appearance, and the vertical and top pieces of this lining are used as the posts and topsill of the door frame; hence an internal door frame is a kind of box, the pieces of which are dove-tailed together, and are thick enough to allow of a rebate being cut in them for the door to shut against. As the efficiency of a door frame depends more on its stiffness than its strength, the scantlings should never be very small; probably 3 × 3 inches is the smallest section that should be given to any solid door frame, and a barrack solid door frame should be 4 × 4 inches. An internal door should be flush with the wall of the room it leads into, and should open into the room.

295. The door itself is composed of a frame of 4 or more pieces, con-

sisting of two verticals, called *styles*, one horizontal at the top, and another at the bottom, called the *top rail* and *bottom rail*, and two more intermediate horizontal pieces called the *lock rail* and *frieze rail*, and sometimes an intermediate style (called moutant, mounting, mullion) to reduce the breadth of the pannelling: according to the mode of filling in this framework the door receives its technical name. The rails are framed in between the styles with common mortises and tenons, driven up tight with little wooden wedges. The intermediate styles are framed in between the rails. The filling in is sometimes of boards or battens nailed against the framework, or let in flush with the framework on one side: this method is generally used with common doors as for barrack rooms, and is called a *framed and battened door*. Sometimes the filling in is of thin panels of wood mortised into the frame with a continuous groove all round; this is used with doors of more important rooms, and is called a *framed and panelled door*. It is the strongest description for ordinary purposes. In large battened doors a diagonal brace is sometimes introduced extending from the upper outer corner to the lower inner corner.

Fig. 1.

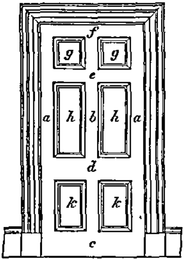
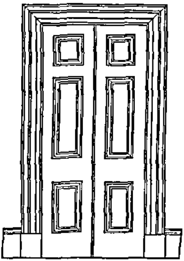


Fig. 2.



In ordinary framed doors, the top and frieze rails are generally of the same width as the styles, the bottom and lock rails generally twice as wide. In *Fig.* 1, *a*, *a* are styles, *b* the moutant, *c* bottom rail, *d* lock rail, *e* frieze rail, *f* top rail, *g* frieze panel, *h* middle panel, *k* bottom panel. When a doorway is closed by two doors of equal width hinged to its oppo-

site jambs, the middle or meeting styles are frequently rebated and beaded; such a door is termed a *double-margined* door or *two-leaved* door. Doors also, which, whilst they are in one width are framed with a wide style in the middle, beaded in the centre in imitation of the two styles of a two-leaved door, are also called double-margined doors. *Fig.* 2 shows the appearance of the two-leaved and double margined doors. A sash door is one which is glazed above the lock rail.

296. Windows.—There are three ordinary methods of arranging the opening of windows, requiring three kinds of construction.

1st. *The Sliding Sash*, in which the window slides vertically up and down in its frame, being counterbalanced by two weights, one on each side, moving in boxes made in the frames and connected with the windows by cords passing over pullies at the top. This is the method commonly used in England, and is the most effective one in climates of much wind and rain. There is a window frame, just as there is a door frame, for the windows to work in, and this is made of four pieces like a door frame, two side pieces, a top sill, and a bottom sill. The side pieces, instead of being solid, consist of the boxes before mentioned, or *cases* as they are called, made of thin boards, the sides of which project slightly towards the window, forming a kind of groove for the window to slide in. The top and bottom sills are cut with a rebate for the window to shut against, and the bottom sill is *weathered*, that is sloped on its upper surface to carry off the rain. The bottom sill is generally of hard wood, on account of its exposure to wet. The frame is made by the carpenter and fixed in its place by the mason or bricklayer.

The window or *sash*, as the joiner calls it, is made like a door, of a frame of four pieces, two styles and two rails: they are put together on the same principles as in a door; the intermediate pieces to hold the panes are called the *sash bars*. The vertical sash bars extend continuously from top to bottom, the horizontal bars are framed in between them. The bars and frame pieces are cut with a rebate on the outer sides forming a shoulder against which the glass is laid; the underside of the bottom rail is bevilled to fit the weatherings of the bottom sill of the window frame.

When the window is in two separate pieces, or is *hung double*, having an upper and a lower sash, each piece is hung separately to a pair of counterbalancing weights, the upper sash slides downwards to open, and the lower sash slides upwards, the upper one being placed outside the

lower one for this object partly. The *meeting rails* of the two sashes are cut with a bevil on the inner and outer edges, respectively, in order that they may fit quite closely when shut.

The size of the panes or intervals of the sash bars are determined by the most convenient and economical sizes of glass which can be obtained. The pullies of the counterbalancing weights are generally made of brass, and the weights of lead, and the cords of a small white rope called, sash cord. The only other fastening required is one connecting the two meeting rails together, which should be such that when open it shall not interfere with the movement of the sash; it is partly for convenience of arrangment of this fastening that the upper sash is placed outside the lower one.

2nd. Casement Windows.—The second method of opening windows is that generally used on the continent, and in Indian houses, of hanging them with hinges to the frame to open like a door. It is very difficult to keep out the weather with this method. The window frame is in this case solid, and is cut with rebates on the side pieces and sills for the windows to shut against, otherwise the frame is made on the same principles as a door frame. The window is generally divided in two parts or *leaves* vertically, like a folding door, in order to reduce the breadth of the moving part. Each part is made of a frame of four pieces with sash bars, but in this case the horizontal bars should extend continously through, and the vertical bars should be framed in between them. Several different methods have been proposed of forming the rebates, and the junction of the two centre styles, with the object of effectually keeping out the rain and wind; the most effective appears to be to make a curved groove in one part, and a corresponding curved tongue or projection on the other, so as to fit close to each other when shut.

Besides the hinges, a fastening similar to a door lock and bolts are required for this window.

3rd. Swinging Windows.—Another method of arranging the opening of a window, common in factories, barracks and any lofty rooms, is by swinging it on two horizontal pivots in the side styles, a little above the centre of their height, so that it is opened and shut by means of two lines, one from the top rail, and one from the bottom, the upper part opening inwards and the lower part opening outwards. This is therefore an advantageous plan for windows, out of ordinary reach of hand. The horizontal sash bars in this window should extend continuously across, and there

should be a centre rail to hold the two pivots. It is easier to make this window water-tight than the casement window, because a rebate forming an effective stop can be cut in the inner side of the top part, and the outer side of the bottom part. It is not applicable to large windows, on account of the strain from the mode of hanging.

The weight and strength of a window depends much on the thickness of the wood work, as in the case of a door; $1\frac{3}{4}$ inches is a suitable thickness for an ordinary barrack window. The sash bars are generally the same thickness as the frame.

297. Staircases.—*Stairs* are constructions composed of horizontal planes elevated above each other, forming steps; affording the means of communication between the different stories of a building

The horizontal part of a step is called the *tread*; the vertical part the *riser;* the breadth or distance from riser to riser, the *going*.

When the steps are narrower at one end than the other, they are termed *winders*.

The wide step introduced as a resting-place in the ascent is *a landing*, and the top of a stair is also so called When the landing at a resting place is square, it is designated a *quarter space*. When the landing occupies the whole width of the staircase it is called a *half space*. So much of a stair as is included between two landings is called a *flight*, especially if the risers are parallel with each other: the steps in this case are *fliers*: the distance from the first to the last riser in a flight, the *going of the flight*.

The raking pieces which support the ends of the steps are called *strings*. The inner one, placed against the wall, is the *wall string*; the other the *front or outer string*. If the front string is mitred or bracketed, it is called an *open string;* if grooved, a *close string*.

Stairs in which the outer string of the upper flight stands directly and perpendicularly over that of the lower flight are called *dog-legged stairs* (*vide Fig.* 1, page 318, and *Plate* XLI); otherwise *newel stairs*, from the fact of a piece of stuff called a *newel*, being used as the axis of the spiral of the stair; the newel is generally ornamented by turning, or in some other way. The outer strings in such stairs are tenoned into the newel, as also are the first and last risers of the flight.

When the vertical planes of the upper and lower strings are separated by an interval, the space is called the *well-hole*, *vide Fig.* 2, page 318.

Where there is a well-hole and no newel, and the string is continued in a curve, the curved part of the string is said to be *wreathed*, and the stair is then a *geometrical stair*.

Besides the support afforded by the strings, the stair is sustained by pieces placed below the fliers; these are called *carriages*; they are composed of longitudinal and transverse pieces; the former are called *rough strings*, the latter *pitching pieces*; and the rough strings have triangular pieces called *rough brackets*, fitted to the underside of the tread and riser.

The winders are supported by rough pieces called *bearers*, wedged into the wall, and secured to the strings.

Where communication between the stories is frequent, the qualities necessary in the stairs are ease and convenience in using, combined with sufficient strength and durability. Economy of space in the construction of stairs is an important consideration. To obtain this, the stairs are made to turn upon themselves, one flight being carried above another at such a height as will admit of head room to a full-grown person. *Plate* XL., shows in plan, section, and elevation, the several timbers referred to above as used in the construction of stairs.

298. *Method of setting out stairs where the building is already erected, or the general plan of the building is understood.* The first objects to be ascertained are the situation of the first and last risers, and the height of the story wherein the stair is to be placed.

A sketch is made of the plan of the hall to the extent of 10 or 12 feet from the supposed place of the foot of the stair, and all the doorways, branching passages, or windows which can possibly come in contact with the stair from its commencement to its expected termination or landing, are noted. This sketch necessarily includes a portion of the entrance-hall in one part, and of the lobby or landing in the other, and on it have to be laid down the expected lines of the first and last risers. The height of the story is next to be exactly determined and taken on a rod; then, assuming a height of riser suitable to the place, a trial is made, by division, how often this height is contained in the height of the story, and the quotient, if there be no remainder, will be the number of risers in the story. Should there be a remainder on the first division, the operation is reversed, the number of inches in the height being made the dividend, and the before-found quotient the divisor, and the operation of division by reduction is carried on, till the height of the riser

is obtained to the thirty second part of an inch. These heights are then set off on the story rod as exactly as possible. The next operation is to show the risers on the plan, but for this no arbitrary rule can be given; the designer must exercise his ingenuity.

299. Whe two flights are necessary for the story, it is desirable that each flight should consist of an equal number of risers; but this will depend on the form of the staircase, the situation and height of the doors, and other obstacles to be passed over or under, as the case may be. Try what the width of the tread will be by setting off, upon the line $n\ a$ in *Fig.* 1, the width of the landing from the wall AB; and dividing the length of the flight into as many equal spaces as it is intended there should be steps in each flight. The landing covers one riser, and therefore the number of steps in a flight will be always one fewer than the number of risers. The width of tread which can be obtained for each flight will thus be found, and, consistent with the situation, the plan will be so far decided. A pitch-board should now be formed to the angle of inclination: this is done by making a piece of thin board in the shape of a right-angled triangle, the base of which is the exact going of the step, and its perpendicular the height of the riser.

If the stair be a newel stair, its width will be found by setting out the plan and section of the newel on the landing; (if one newel, it should, of course, stand in the middle of the width;) then, in connection with the newel, mark the place of the outer or front string, and also the place of back or wall string, according to the intended thickness of each. This should be done not only to a scale on the plan, but likewise to the full size on the rod. Set off on the rod, the thickness of each string; the depth of the grooving of the steps in the string; mark also on the plan the place and section of the bottom newel; the same figure answers for the place of the top newel of the second flight, the flights being supposed of equal length. The front string is usually framed into the middle of the newel, and thus the centres of the rail, the newels, the balusters, and the front string range with each other; the width of the flights will thus be shown on the rod.

It is a general maxim that the greater the breadth of a step the less should be the height of the riser; and experience shows that a step of 12 inches width and $5\frac{1}{2}$ inches rise, may be taken as a standard.

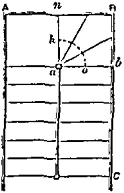
300. *Plans of Stairs.*—Before giving examples of the various forms

of stairs ordinarily occurring in practice, we shall, with some minuteness, illustrate the mode of laying down the plan of a stair, where the height of the story, the number of the steps, and the space which they are to occupy, are all given.

The first example shall be *of the simplest kind, or dog-legged stairs.*

Let the height (*Fig.* 1) be 10 feet, the number of risers 17, the height of each riser consequently $7\frac{1}{17}$, and the breadth of tread $9\frac{1}{2}$; the width of the staircase 5 feet 8 inches.

Fig 1.

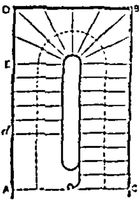


Proceed first to lay down on the plan the width of the landing; then the size of the newel *a* in its proper position, the centre of the newel being *on the riser line of the landing, which should be* drawn at a distance from the back wall equal to the semi-width of the staircase, and at right angles to the side wall. Bisect the last riser *a b* at *o*, and describe an arc from the centre of the newel, as *o h*, on which set out the breadth of the winders; then to the centre of the newel, draw the lines indicating the face of each riser. If there be not space to get in the whole of the steps, winders may be also introduced on the left hand side, instead of the quarter space as shown.

301. The next example is a geometrical staircase.

Let A D B C (*Fig.* 2) be the plan of the walls where a geometrical stair is to be erected, and the line C be *the line of the face of the first* riser; let the whole height of the story be 11 feet 6 inches, and the height of riser 6 inches, the number of risers will consequently be twenty-three. The number of steps in each flight will be one fewer than the number of risers, and according to the preceding rule, the tread should be 11 inches, so if there are two flights there will be twenty-one steps; or if winders are necessary, there will be twenty-two steps in all, from the first to the last riser. Having first set out the opening of the well-hole, or the line of balusters, divide the width of the stairs into two equal parts, and continue the line of division with a semicircle round the circular part, as shown by the

Fig. 2.



dotted line in the figure; then divide this line from the first to the last riser into twenty-two equal parts, and if a proper width for each step can thus be obtained, draw the lines for the risers. This would, however, give a greater width of step than is required; take therefore 11 inches for the width of step, and this repeated twenty times, will reach to the line *d*, which is the last riser. There are, in this case, eight winders in the half space, but four winders might be placed in one quarter space, the other quarter space might be made a landing, and the rest of the steps being fliers, would bring the last riser to the line AC. The usual place for the entrance to the cellar stairs is at D, but allowing for the thickness of the carriages, the height obtainable there will be only about 6 feet, which is not sufficient. At E, in this example, would be a better situation for the entrance to the cellar steps.

302. *Plate* XLI., *Fig.* 1.—Nos. 1 and 2, show a plan and elevation of a newel stair. The first quarter space contains three winders, the next quarter space is a landing; the lower flight is shown partly in section, exposing the rough string DD, and its connection with the bearers CC. The front string AA should be tenoned into the newels below and above.

Fig. 2.—Nos. 1 and 2 show the plan and elevation of a well-hole stairs, with a landing in the half space. The well-hole is here composed of two circular quadrants connected by a small portion of straight line; this figure is not so graceful as the perfect semicircle in *Fig.* 2, page 318, but it allows more room on the landing.

303. *Plate* XLII., *Fig.* 1.—Nos. 1 and 2 are the plan and elevation of a geometrical stair, composed of straight flights, with quarter-space landings, and rising 15 feet 9 inches.

The first flight is shown in *Fig.* 1, No. 2, partly in section, exhibiting the carriage *c c*, T the trimmer joists for quarter space, and V the trimmer joists of the floor below, with the lower end of the iron baluster fastened by a screw and nut *d*, at the under side of the trimmer joists V.

Fig. 2.—No. 1, exhibits the plan, and No. 2, the elevation of a geometrical stair, with straight flights connected by winders on the quarter spaces.

SECTION IV.—MASONRY.

304. MASONRY is the art of raising structures in Stone or Brick, and Mortar.

Masonry is classified either from the nature of the material, as *Stone Masonry*, *Brick Masonry*; or from the manner in which the material is prepared, as *Cut Stone* or *Ashlar Masonry*, *Rubble Stone* or *Rough Masonry*, and *Hammered Stone Masonry*; and in India, *Pucka*, *Kucha Pucka*, and *Kucha*, Brick Masonry; the first, consisting of burnt bricks set in lime mortar; the second, of burnt bricks in mud; and the third, of sun-dried bricks set in mud.

CHAPTER XVI.

STONE MASONRY.

305. *Ashlar*.—Masonry of cut stone, when carefully made, is stronger and more solid than that of any other class; but, owing to the labor required in *dressing*, or preparing the stone, it is also the most expensive. It is, therefore, chiefly restricted to those works where a certain architectural effect is to be produced by the regularity of the masses, or when great strength is indispensable.

Before explaining the means to be used to obtain the greatest strength in cut stone, it will be necessary to give a few definitions to render the subject clearer.

In a wall of masonry, the term *face* is usually applied to the front or outside of the wall, and the term *back* to the inside; the stone which forms the front, is termed the *facing*; that of the back, the *backing*; and the in-

terior, the *filling*. If the front, or back of the wall, has a uniform slope from the top to the bottom, this slope is termed the *batter*. The term *course* is applied to each horizontal layer of stone in the wall: if the stones of each layer are of equal thickness throughout, it is termed *regular coursing;* if the thickness is unequal, the term *random*, or *irregular coursing*, is applied. The *sides* are the surfaces which bound the stones in a direction transverse to both faces and beds. The joints between the courses through which the principal pressures act are called *bed-joints:* the joints transverse both to beds and face are termed *side-joints*, or often simply *joints*. The surfaces of the stones of each course parallel to the layers are termed the *beds* or *builds*. The arrangement of the different stones of each course or of contiguous courses, is termed the *bond*.

306. The strength of a mass of cut stone masonry will depend on the size of the blocks in each course, on the accuracy of the dressing, and on the bond used.

Ashlar.—The size of the blocks varies with the kind of stone, and the nature of the quarry. From some quarries the stone may be obtained of any required dimensions; others, owing to some peculiarity in the formation of the stone, only furnish blocks of small size. Again, the strength of some stones is so great as to admit of their being used in blocks of any size, without danger to the stability of the structure, arising from their breaking; others can only be used with safety, when the length, breadth, and thickness of the block bear certain relations to each other. No fixed rule can be laid down on this point; that usually followed by builders, is to make, with ordinary stone, the breadth at least equal to the thickness, and seldom greater than twice this dimension, and to limit the length to within three times the thickness. When the breadth or the length is considerable, in comparison with the thickness, there is danger that the block may break, if any unequal settling, or unequal pressure, should take place. As to the absolute dimensions, the thickness is generally not less than one foot, nor greater than two; stones of this thickness, with the relative dimensions just laid down, will weigh from 1,000 to 8,000 pounds, allowing, on an average, 160 pounds to the cubic foot. With these dimensions, therefore, the weight of each block will require a very considerable power, both of machinery and men, to set it on its bed.

307. Block-in-course.—When the stones are smaller, the depth of

the courses being from 7 to 9 inches, such masonry of uniform, ham dressed, blocks is termed *block-in-course* masonry.

308. *Coping.*—For the coping and top courses of a wall, the same objections do not apply to excess in length; but this excess may, on the contrary, prove favorable; because the number of top joints being thus diminished, the mass beneath the coping will be better protected, being exposed only at the joints, which cannot be made water-tight, owing to the mortar being crushed by the expansion of the blocks in warm weather, and, when they contract, being washed out by the rain.

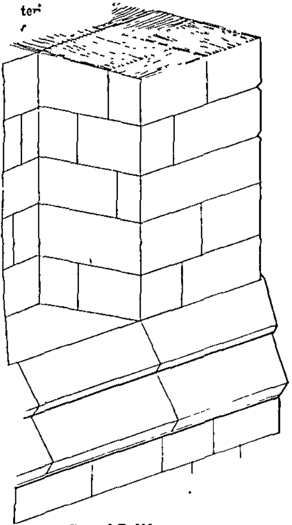
309. The closeness with which the blocks fit is solely dependent on the accuracy with which the surfaces in contact, are wrought or *dressed;* if this part of the work is done in a slovenly manner, the mass will not only present open joints from any inequality in the settling; but, from the courses not fitting accurately on their beds, the blocks will be liable to crack from the unequal pressure on the different points of the block.

The surfaces of one set of joints should, as a prime condition, be perpendicular to the direction of the pressure; by this arrangement, there will be no tendency in any of the blocks to slip. In a vertical wall, for example, the pressure being downward, the surfaces of one set of joints, which are the *beds*, must be horizontal. The surfaces of the other set must be perpendicular to these, and, at the same time, perpendicular to the face, or to the back of the wall, according to the position of the stones in the mass. Two essential points will thus be attained; the angles of the blocks, at the top and bottom of the course, and at the face or back, will be right angles, and the block will therefore be as strong as the nature of the stone will admit. The principles here applied to a vertical wall, are applicable in all cases, whatever may be the direction of the pressure and the form of the exterior surfaces, whether plane or curved.

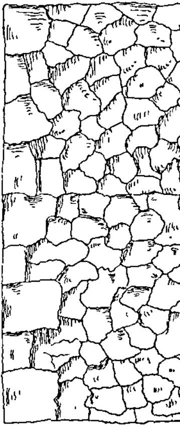
Workmen, unless narrowly watched, seldom take the pains necessary to dress the beds and joints accurately; on the contrary, to obtain what are termed *close joints*, they dress the joints with accuracy a few inches only from the outward surface, and then chip away the stone towards the back, or *tail*, so that, when the block is set, it will be in contact with the adjacent stones, only throughout this very small extent of bearing surface. This practice is objectionable under every point of view; for, in the first place, it gives an extent of bearing surface, which, being generally inadequate to resist the pressure thrown on it, causes the block to splinter off at

STONE MASONRY.

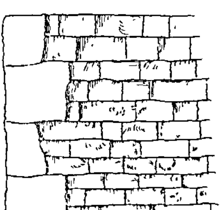
Buttress of Ashlar Masonry



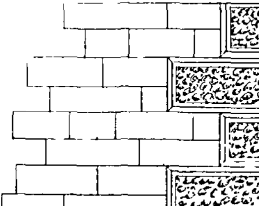
Uncoursed Rubble.



Coursed Rubble



Ashlar with rusticated chamfered quoi



the joint; and in the second place to give the block its proper set, it has to be propped beneath by small bits of stone, or wooden wedges, an operation termed *pinning-up*, or *under-pinning*, and these props, causing the pressure on the block to be thrown on a few points of the lower surface, instead of being equally diffused over it, expose the stone to crack.

When the facing is of cut stone, and backing of rubble, the method of thinning off the block may be allowed for the purpose of forming a better bond between the rubble and ashlar; but, even in this case, the block should be dressed true on each joint, to at least one foot back from the face. If there exists any cause, which would give a tendency to an outward thrust from the back, then, instead of thinning off all the blocks towards the tail, it will be preferable to leave the tails of some thicker than the parts which are dressed.

310. *Bond.*—Various methods are used by builders for the bond of cut stone. The system, termed *headers* and *stretchers*, in which the vertical joints of the blocks of each course alternate with the vertical joints of the courses above and below it, or as it is termed *break joint* with them, is the most simple, and offers in most cases, all requisite solidity. In this system, the blocks of each course are laid alternately with their greatest and least dimensions to the face of the wall: those which present the longest dimension along the face, are termed *stretchers;* the others, *headers.* If the header reaches from the face to the back of the wall, it is termed a *through;* if it only reaches part of the distance, it is termed a *binder.* The vertical joints of one course are either just over the middle of the blocks of the next course below, or else, at least four inches on one side or the other of the vertical joints of that course; and the headers of one course rest as nearly as practicable on the middle of the stretchers of the course beneath. If the backing is of rubble, and the facing of cut stone, a system of throughs or binders, similar to what has just been explained, *must* invariably be used.

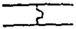
By the arrangement here described, the facing and backing of each course are well connected; and, if any unequal settling takes place, the vertical joints cannot open, as would be the case were they in a continued line from the top to the bottom of the mass; as each block of one course confines the ends of the two blocks on which it rests in the course beneath.

Quoins or corner stones, which should be of large size and chosen with especial care, are at once headers and stretchers: each quoin being a header

relatively to one of the two faces of the building which it connects, and a stretcher relatively to the other.

311. *Cramps and Dowels.*—In masses of cut stone exposed to violent shocks, as those of which light-houses, and sea-walls in very exposed positions are formed, the blocks of each course require to be not only very firmly united with each other, but also with the courses above and below them. To effect this, various means have been used. The beds of one course are sometimes arranged with projections which fit into corresponding indentations of the next course. *Copper Cramps* in the form of the letter S, or in any other shape that will answer the purpose of giving them a firm hold on the blocks, are let in to the top of two blocks of the same course at a vertical joint, and are firmly set with melted lead, or with bolts, so as to confine the two blocks together. Holes are, in some cases, drilled through several courses, and the blocks of these courses are connected by strong bolts fitted to the holes.

Stones are said to be *joggled* together when a projection is worked out on one stone to fit into a corresponding hole or groove in the other (*see* figure). But this occasions great labor and waste of stone,



and *dowel-joggles* are chiefly made use of, which are hard pieces of stone, cut to the required size, and let into corresponding mortices in the two stones to be joined together.

Dowels are pins of wood or metal used to secure the joints of stone-work in exposed situations, as copings, pinnacles, &c. The best material is copper; but the expense of this metal causes it to be seldom used. If iron be made use of, it should be thoroughly tinned to prevent oxidation, or it will, sooner or later, burst and split the work it is intended to protect.

Dowels are often secured in their places with lead poured in from above, through a small channel cut in the side of the joint for that purpose; but a good workman will eschew lead, which too often finds its way into bad work, and will prefer trusting to very close and workmanlike joints, carefully fitted dowels, and fine mortar; dowels should be made tapering at one end, which ensures a better fit, and renders the setting of the stone more easy for the workman.

Iron cramps are used as fastenings on the tops of copings, and in similar situations; but they are not to be recommended, as they are very unsightly, and, if they once become exposed to the action of the atmos-

phere, are powerfully destructive agents. Cast-iron is, however, less objectionable than wrought-iron for this purpose.

312. *Dressing Stone.*—The manner of dressing stone belongs to the stone-cutter's art, but the engineer should not be inattentive either to the accuracy with which the dressing is performed, or the means employed to effect it. The tools chiefly used by the workman are the chisel, axe, and hammer for *knotting*. The usual manner of dressing a surface, is to cut *draughts* around and across the stone with the chisel, and then to use the chisel, the axe with a serrated edge, or the knotting hammer, to work down the intermediate portions into the same surface with the draughts. In performing this last operation, the chisel and axe should alone be used for soft stones, as the grooves on the surface of the hammer are liable to become choked by a soft material, and the stone may in consequence be materially injured by the repeated blows of the workman. In hard stones this need not be apprehended.

The finely grained stones are usually brought to a smooth face, and rubbed with sand to produce a perfectly even surface.

In working soft stones, the surface is brought to a smooth face with the *drag*, which is a plate of steel, indented on the edge like the teeth of a saw, to take off the marks of the tools employed in shaping it.

The harder and more coarsely grained stones are generally *tooled*, that is, the marks of the chisel are left on their face. If the furrows left by the chisel are disposed in regular order, the work is said to be *fair-tooled*, but if otherwise, it may be *random-tooled*, or *chiselled*, or *boasted*, or *pointed*. If the stones project beyond the joints, the work is said to be *rusticated*.

Granite and gritstone are chiefly worked with the scabbling hammer. In massive erections, where the stones are large, and a bold effect is required, the fronts of the blocks are left quite rough, as they come out of the quarry, and the work is then said to be *quarry pitched*.

It what manner soever the faces of ashlar stones are dressed, or even should they be "quarry-faced," there ought to be a chisel-draught round the edges of the face, forming sharp and straight edges with the chisel-draught of the beds and joints, in order that the stone may be accurately set.

313. *Scaffolding.*—The Scaffolding used for stone-work is similar to that described in the next Chapter for brick-work, except that it is double,

relatively to one of the two faces of the building which it connects, and a stretcher relatively to the other.

311. *Cramps and Dowels.*—In masses of cut stone exposed to violent shocks, as those of which light-houses, and sea-walls in very exposed positions are formed, the blocks of each course require to be not only very firmly united with each other, but also with the courses above and below them. To effect this, various means have been used. The beds of one course are sometimes arranged with projections which fit into corresponding indentations of the next course. *Copper Cramps* in the form of the letter S, or in any other shape that will answer the purpose of giving them a firm hold on the blocks, are let in to the top of two blocks of the same course at a vertical joint, and are firmly set with melted lead, or with bolts, so as to confine the two blocks together. Holes are, in some cases, drilled through several courses, and the blocks of these courses are connected by strong bolts fitted to the holes.

Stones are said to be *joggled* together when a projection is worked out on one stone to fit into a corresponding hole or groove in the other (*see* figure). But this occasions great labor and waste of stone, and *dowel-joggles* are chiefly made use of, which are hard pieces of stone, cut to the required size, and let into corresponding mortices in the two stones to be joined together.

Dowels are pins of wood or metal used to secure the joints of stone-work in exposed situations, as copings, pinnacles, &c. The best material is copper; but the expense of this metal causes it to be seldom used. If iron be made use of, it should be thoroughly tinned to prevent oxidation, or it will, sooner or later, burst and split the work it is intended to protect.

Dowels are often secured in their places with lead poured in from above, through a small channel cut in the side of the joint for that purpose; but a good workman will eschew lead, which too often finds its way into bad work, and will prefer trusting to very close and workmanlike joints, carefully fitted dowels, and fine mortar; dowels should be made tapering at one end, which ensures a better fit, and renders the setting of the stone more easy for the workman.

Iron cramps are used as fastenings on the tops of copings, and in similar situations; but they are not to be recommended, as they are very unsightly, and if they once become exposed to the action of the atmos-

phere, are powerfully destructive agents. Cast-iron is, however, less objectionable than wrought-iron for this purpose.

312. *Dressing Stone.*—The manner of dressing stone belongs to the stone-cutter's art, but the engineer should not be inattentive either to the accuracy with which the dressing is performed, or the means employed to effect it. The tools chiefly used by the workman are the chisel, axe, and hammer for *knotting.* The usual manner of dressing a surface, is to cut *draughts* around and across the stone with the chisel, and then to use the chisel, the axe with a serrated edge, or the knotting hammer, to work down the intermediate portions into the same surface with the draughts. In performing this last operation, the chisel and axe should alone be used for soft stones, as the grooves on the surface of the hammer are liable to become choked by a soft material, and the stone may in consequence be materially injured by the repeated blows of the workman. In hard stones this need not be apprehended.

The finely grained stones are usually brought to a smooth face, and rubbed with sand to produce a perfectly even surface.

In working soft stones, the surface is brought to a smooth face with the *drag,* which is a plate of steel, indented on the edge like the teeth of a saw, to take off the marks of the tools employed in shaping it.

The harder and more coarsely grained stones are generally *tooled,* that is, the marks of the chisel are left on their face. If the furrows left by the chisel are disposed in regular order, the work is said to be *fair-tooled,* but if otherwise, it may be *random-tooled,* or *chiselled,* or *boasted,* or *pointed.* If the stones project beyond the joints, the work is said to be *rusticated.*

Granite and gritstone are chiefly worked with the scabbling hammer. In massive erections, where the stones are large, and a bold effect is required, the fronts of the blocks are left quite rough, as they come out of the quarry, and the work is then said to be *quarry pitched.*

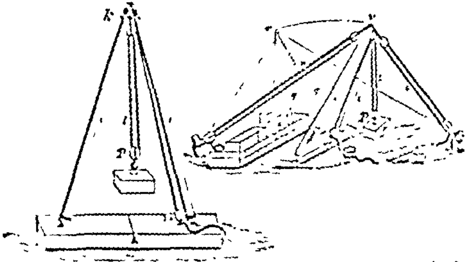
It what manner soever the faces of ashlar stones are dressed, or even should they be "quarry-faced," there ought to be a chisel-draught round the edges of the face, forming sharp and straight edges with the chisel-draught of the beds and joints, in order that the stone may be accurately set.

313. *Scaffolding.*—The Scaffolding used for stone-work is similar to that described in the next Chapter for brick-work, except that it is double,

that is formed with two rows of standards so as to be totally independent of the walls for support. The construction of scaffolds with round poles lashed with cords, has lately been superseded in large works by a system of scaffolding of square timbers connected by bolts and dog-irons.

The hoisting of the materials is performed from these scaffolds by means of a travelling crane, which consists of a double travelling carriage, the lower one running on a tramway formed on stout sills laid on the top of two parallel rows of standards; on this lower carriage, is placed a short tramway, laid transversely to the direction of the rows of standards; a smaller carriage again runs on these rails and carries a crab-winch by which the materials are raised; by the combined motion of the two carriages, the lower moving *along* the line of standards and the upper *across* it, the material can be brought with great ease and precision over any part of the work lying between the two rows of standards.

314. *Shears.*—Smeaton, in his published account of the operations and proceedings during the building of the Eddystone Light-house, describes a most excellent form of shears, that is simple and admirably suited to the moving and placing of heavy stones on walls, or other buildings. It consists of a heavy block of timber *h*, and two spars *i*, *i*, disposed in the form shown below; the bottom piece *h* is square, and may be from 12 to 15 feet long, and should be sound and hard. The shears consist of the two spars



[illegible] as [illegible] round, tapering, and as long as they can be [illegible] [illegible] from 28 to 30 feet. Their lower ends are [illegible] with the

bottom piece, *h*, by two very strong iron eyes or links, loose enough to permit motion, while their upper ends meet, and are connected by the strong iron pin *k*, which passes through both of them, and also serves to support the top hook of the blocks and *fall l*, the running rope of which passes downwards from the upper block, and takes a course close to one of the poles, and is passed through the snatch block *m*, fixed to the bottom piece *h*, and to this rope the workmen apply their strength immediately, or through the agency of a crab, or windlass, according to the force to be overcome. The central point of the horizontal piece *h*, is marked on its top, at the point to which the bottom block would descend, when the piece is set truly level.

To use this apparatus, the bottom or foundation piece *h* is set truly level upon hard ground, or is supported on piles or timber skids, if the ground is not hard enough to sustain the load; and the spars are retained in their vertical or other required position, by two sets of running blocks and falls, pulling in opposite directions, and at right angles to the direction of the length of the foundation piece *h*, as may be better seen in the perspective view of the same machine as fixed for use. The upper ends of the guy tackle are attached to the tops of the spars, and their lower ends to strong posts fixed in the ground, or to stumps of trees, parts of buildings, or anything that will afford stability. Then by lowering out the fall *n*, and tightening that at *o*, the shears may be made to incline or bend over, as shown in the figure, until the bottom block *p* hangs directly over a stone, *r*, that has to be lifted, and thus this stone may be taken off the ground, and raised to any required height, by the principal blocks and fall, *p l*. That done, the guy fall *o* is slacked while *n* is tightened, so that the shears are first brought into a vertical position, and afterwards allowed to turn over or incline to the other side, as shown by the dotted lines *q q*, when the sustaining force will be transferred to the guy fall *o*, and *n* will become useless; *and in this way a stone may be brought from the ground* upon which it was worked, directly over the place, *s*, in the wall in which it has to be deposited, without disengaging it at all from the block by which it was first lifted, and without hand-barrows, or any trouble whatever.

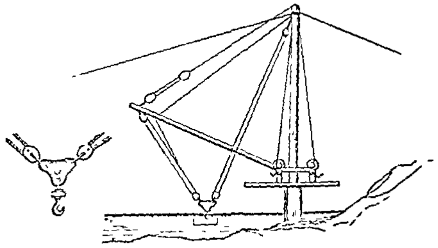
To insure the delivery of the stone into its proper place by this machine, a line must be strained from the centre of the stone to be moved, to a point perpendicularly under the centre of the place in which the stone has to be placed, and the foundation piece, *h*, of the shears must be moved until its

central marked point, *t*, falls under the line, while the length of the piece is at right angles to it; the foundation piece must then be fixed in this position by driving short stakes round it into the ground, and then the upper end of the shears in moving, will describe an arc of a circle *v v*, the plane of which will pass through the centre of the stone, and the centre of the bed or position in which it is to be placed.

315. *Derrick.*—The movable derrick crane is also much used in setting masons' work. It consists of a vertical post, supported by two timber backstays, and a long movable jib or derrick hinged against the post below the gearing.

By means of a chain passing from a barrel over a pulley at the top of the post, the derrick can be raised from a horizontal to an almost vertical position, thus enabling it to command every part of the area of a circle of a radius nearly equal to the length of the derrick. This gives it a great advantage over the old gibbet crane, which only commands a circle of a fixed radius, and the use of which entails great loss of time from its constantly requiring to be shifted as the work proceeds.

316. In the American derrick represented in the figure, the mast is supported in a vertical position by four guys attached to a ring on a cast-iron cap on its head. Below this ring, and revolving freely upon the cap, is a wrought-iron frame containing two sheaves of cast-iron. The lower part of the mast is rounded above a shoulder. A revolving frame of wood,



embracing the mast and carrying two rope-barrels with gearing and winches, rests upon the shoulder. The boom is stepped into the upper

part of this frame, and a light platform for the winch-men is secured to the lower part, so that boom, platform, and winches, all revolve together round the mast. Booms 50 feet in length are commonly used; the outer end is supported by a topping-lift secured to the revolving iron frame on the cap at the head of the mast.

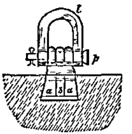
Two tackles are used, one suspended at the outer end of the boom, the other to the frame at the mast-head. Both falls lead over the sheaves at the mast head, and thence to the winch-barrels. The lower blocks of the tackles are attached to two corners of a triangular plate, the third carrying a hook, as seen in the figure. It will be evident, that by hauling upon or slacking the falls alternately, the stone suspended from both can be placed directly at the foot of the mast or under any point of the boom; and as the latter revolves, any point within a circle whose radius equals the boom can be reached.

The foot of the mast is usually raised upon a blocking of timber, some slight braces sufficing to prevent the step from sliding. Three 50 feet booms placed so that their circles intersect, will place every stone in a large building, or a sea-wall 300 feet long. A word or sign to the winch-men serves to direct them, and the stone moves to its place with the utmost precision, and as gently and quietly as a feather.

An American derrick was used to lay the 6-ton concrete blocks for the coffer-dam at the Light-house on the "Prongs" (Bombay). The platform was made to rest on cannon balls, which allowed it to revolve easily. Mast about 70 feet high, jib about 45 feet.

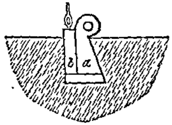
In long sea walls, an excellent means of laying the stones of the ashlar facing is to have a hollow truck running on rails, with a frame over it from which the stone is lowered between the rails by a Weston block.

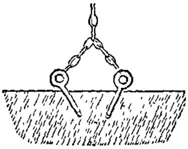
317. *Lewis.*—In hoisting blocks of stone they are attached to the tackle by means of a simple contrivance made of iron, and called a *lewis*, which is shown in the annexed figure.



A hole tapering upwards, about 3 inches deep having been cut in the upper surface of the stone to be raised, the two tapering side pieces, *a*, *a*, of the lewis are inserted, and placed against the sides of the hole; the

centre parallel piece, *b*, is then inserted, and secured in its place by a pin, *p*, passing through all three pieces, and the ends of a loop, *l*, which embraces their heads. The stone may be then safely hoisted by the loop *l*, as it is impossible for the lewis to draw out of the hole. By means of the lewis, in a slightly altered form, as shown in figure, stones can be lowered and set under water without difficulty, and the lewis disengaged by means of a line attached to the parallel piece *b* the removal of which allows the other to be drawn out of the mortice. The next figure shows a substitute for a lewis, consisting of two pins let into holes which they closely fit, sloping towards each other. When a strain is applied to the lifting chain, these pieces jam in their places and support the weight of the stone.





When a block of cut stone is to be laid, the first point to be attended to, is to examine the dressing, which is done by placing the block on its bed, and seeing that the joints fit close, and the face is in its proper plane. If it be found that the fit is not accurate, the inaccuracies are marked, and the requisite changes made. The bed of the course, on which the block is to be laid, is then thoroughly cleansed from dust, &c., and well moistened; a bed of thin mortar is laid evenly over it, and the block, the lower surface of which is first cleansed and moistened, is laid on the mortar-bed and well settled, by striking it with a wooden mallet. When the block is laid against another of the same course, the joint between them is prepared with mortar in the same manner as the bed.

318. Coursed Rubble Masonry consists of a series of horizontal courses, not less than 6 inches thick, each of which is correctly levelled before another is built upon it; but the side-joints are not necessarily vertical. *One-fourth part* at least of the face in each course should consist of bond-stones or headers; each header to be of the entire depth of the course, of a breadth ranging from $1\frac{1}{2}$ times to double that depth, and of a length extending into the building to from 3 to 5 times that depth,

as in ashlar. These headers should be roughly squared with the hammer, and their beds hammer-dressed to approximate planes; and care should be taken not to place the headers of successive courses above each other; for that arrangement would cause a deficiency of bond in the intermediate parts of the course.

Care should be taken, not only that each stone shall rest on its natural bed, but that the sides parallel to that natural bed shall be the largest, so that the stone may lie flat, and not be set on edge or on end. However small and irregular the stones may be, care should be taken to make the courses break joint. Hollows between the larger stones should be carefully filled with smaller stones, completely imbedded in mortar.

Coursed rubble masonry requires great care in the inspection of its progress, to see that the preceding rules are observed: and especially, that the interior of the wall contains neither empty hollows, nor spaces filled wholly with the mortar or with rubbish where pieces of stone ought to be inserted, and that each stone is laid flat, and on its natural bed. Care must be taken that the headers or bond-stones are really what they profess to be, and not thin stones set on edge at the face of the wall.

319. Common Rubble Masonry differs from coursed rubble in not being built in courses; but in other respects the same rules are to be observed. The resistance of common rubble to crushing is not much greater than that of the mortar which it contains, it is, therefore, not to be used where strength is required, unless built with strong hydraulic mortar. Its chief use in engineering is for fence walls.*

To connect the parts well together, and to strengthen the weak points, throughs or binders should be used in all the courses; and the angles (or *quoins*) should be constructed of cut or hammered stone.

320. The following is the specification for the Ashlar Stone-work used on the Jubbulpore Branch of the E. I. Railway, and will be found a good guide for similar work elsewhere.—

Ashlar.—Will be of two kinds—1st, Smooth-faced or tooled ashlar, and 2nd, Fair broached and Rock-faced ashlar, with or without a chisel draft round the edges: the rock-facing where used, not to project more than 2 inches beyond the face of the chisel draft or arris.

It is proposed to use but a limited proportion of this class of work, which will be principally confined to imposts, bed plates for girders, springers, string courses and copings, and occasionally in quoins and walling, and large arches, but power is reserved to use it wherever it may be deemed necessary.

* *See* para. 450 for remarks on common rubble Masonry as used for Masonry Dams.

Thickness of Ashlar Courses, and general arrangement.—No course of ashlar to be less than 8 inches thick. One-third of the entire length of each course to be headers. No stone to be less than 2 feet long, and when the thickness of the course does not exceed 10 inches, the stones must not be less than 15 inches on the bed. Where the thickness of the ashlar courses *exceeds* 10 inches, the breadth of the beds will not be less than a third more than the thickness of the course.

No header to be of less length than 18 inches in excess of the breadth of the course of ashlar to which it belongs. In walls up to 3 feet thick, all headers to be through stones. The beds and joints of all ashlar stones to be dressed perfectly true, square and full. No hollow beds will be allowed.

The vertical joints in all cases to be dressed true and square for at least two-thirds of the breadths of the beds in from the face of the work.

No joint to exceed three-sixteenths of an inch in thickness.

The courses to be arranged with as much uniformity as possible, and laid perfectly horizontal, the lighter courses being kept towards the top of the structure.

The vertical joints of each course not to have less than 6 inches lap over the joints of the course next below. The work to be thoroughly well grouted after every course.

Ashlar in Copings.—The coping stone will as a rule be dowelled, but the Engineer may dispense with this system in such cases as he may deem expedient.

No stones in the ashlar copings to be less than 2 feet 6 inches long, and the exposed surfaces to be dressed to a smooth face.

Large Rough Stone Blocks.—It may be necessary to use one or more courses of rough stone blocks in the foundations of bridges; such blocks to be only quarry scabbled, and none less than 8 inches thick, or less than 8 square feet in area. These blocks to be measured half as ashlar, half as rubble; they are to be laid in mortar, and great care is to be taken that they rest evenly on their beds.

321. The following is a very good specification for Stone Masonry, drawn up by Mr. C. Campbell, C. E., when Superintending Engineer in the Central Provinces, for use in the Jubbulpore Circle:—

As much confusion is caused by Engineers and stone masons attaching widely different meanings to such words as "rubble," "block-in-course," &c., the use of such terms will be discontinued, and the stone work in the Jabalpúr Circle will always be specified under one of three heads, viz., ordinary stone work, coursed stone work, and dressed stone.

Ordinary stone work.—No stone will be less than 5 inches thick, nor will it contain less than three-eighths of a cubic foot. The largest stones will be selected for the face; they will be set flush in mortar, headers and stretchers alternately, the former projecting at least 5 inches beyond the latter. Every sixth header in walls up to 2½ feet thickness will be a through stone, and in walls beyond that thickness will be 2½ feet long. The interior will be filled in with good stones set as close as possible, well flushed in mortar, the interstices being closely packed with sound spalls. The work will be brought to a level bed every 18 inches, grouted and made perfectly solid.

A layer of flat stones, extending the whole breadth of the wall, will be laid at intervals of 6 feet in height, and specially at the floor line and under all girders and roof trusses.

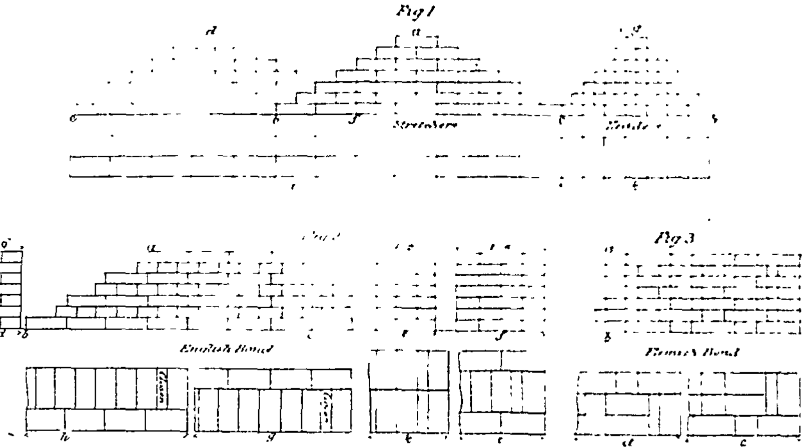
CHAPTER XVII.

BRICK MASONRY.

322. WITH good bricks and mortar, this kind of masonry is quite as durable, if not so strong, as ordinary stonework, while it is generally more economical. In native structures built with small bricks and a profuse expenditure of the best mortar, the strength of brick masonry is generally quite independent of the bond, but with the larger bricks now in general use, the bond should receive as much attention as in stone masonry.

Bond.—The great art in bricklaying is to preserve and maintain a bond, to have every course perfectly horizontal, both longitudinally and transversely, and perfectly plumb; which last, however, may not mean upright, though that is the general acceptation of the term, for the plumb-rule may be made to suit any inclination that it is wished the wall may have, as inward against a bank, for instance, or in a tapering tower; and also to make the vertical joints recur perpendicularly over each other. By *bond* in brickwork, is intended that arrangement which shall make the bricks of every course cover the joints of those in the course below it, and so tend to make the whole mass or combination of bricks act as much together, or dependently one upon another, as possible. The object of this will be understood by reference to *Plate* XLIV., *Fig.* 1. Here it is evident, from the arrangement of the bricks, that any weight placed on *a* would be carried down and borne alike in every course from *b* to *c*; in the same manner the brick *d* is up borne by every brick in the line *e f*; and so throughout the structure. But this forms a longitudinal bond only, which cannot extend its influence beyond the width of the brick; and a wall of one brick and a half or two bricks thick, built in this manner, would in effect, consist of three or four half-brick-thick walls, acting independently of each other, as shown in the plan at *i*. If the bricks were turned so as to show their short sides or ends in front, instead of their long ones,

BRICK MASONRY



because, by the use of it, uniformity of appearance is preserved, and whole bricks are retained on the quoins or angles. In walls of almost all thicknesses above nine inches, to preserve the transverse, and yet not destroy the longitudinal bond, it is frequently necessary to use half bricks; but it becomes a question whether more is not lost in the general firmness and consistence of the wall by that necessity, than is gained in the uniformity of the bond. It may certainly be taken as a general rule, that a brick should never be cut if it can be worked in whole, for a new joint is thereby created in a construction, the difficulty of which consists in obviating the debility arising from the constant recurrence of joints. Great attention should be paid to this, especially in the quoins of buildings, in which half bricks most readily occur; and there it is not only of consequence to have the greatest degree of consistence, but the quarter bricks used as closers are already admitted, and the weakness consequent on their admission would only be increased by the use of other batts, or fragments of bricks.

324. The accompanying woodcuts show in fuller detail the various modes of arranging bricks in English Bond, where one wall meets another at right angles. *Fig.* 1 shows the section of a superstructure wall, 1 brick thick, carried on a foundation wall, $1\frac{1}{2}$ bricks thick. *Fig.* 2 shows the arrangement of the lowest course in the superstructure: a half brick *header* on one side and a half-brick *stretcher* on the other side being used as *closers* to prevent the joints co-inciding with those of the course above.

Fig. 1.

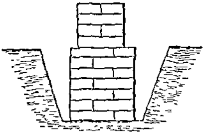


Fig. 2.

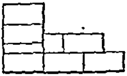


Fig 3.

In *Fig.* 3, the second course of the superstructure is shown, and the arrangement on each side is reversed.

It will be observed that in each stretcher course, the longitudinal joint

is continuous throughout the whole length of wall. *Figs.* 4 and 5 show

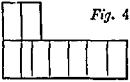


Fig. 4.

Fig. 5.

another slightly different mode of arranging the bricks in their two courses; by which the number of *closers* in each course at the quoin is reduced from two to one.

Figs. 6 and 7 illustrate the alternate course of the foundation in the wall

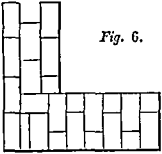


Fig. 6.

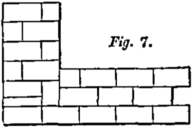


Fig. 7.

shown in *Fig.* 1. Here also half and three-quarter *batts* are used as closers to break the continuity of both the horizontal and vertical joints. It will be observed that in each of these courses *one-sixth* of the bricks are half bricks, thus enabling the builder to utilize the broken bricks, a number of which must be expected to occur in every cart load brought to the works from the kilns. Three continuous longitudinal joints extend throughout each stretcher course. Another arrangement of the bricks in these same courses is shown in *Figs.* 8 and 9: where the use of half bricks

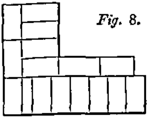


Fig. 8.

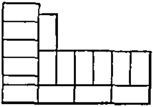


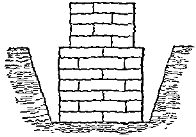
Fig. 9.

(except as closers at the courses) is entirely obviated. The number of joints is thereby diminished, and the work consequently rendered somewhat stronger, but the opportunity of utilizing the inevitable proportion of half bricks in the supply from kilns is lost. It will depend upon cir-

cumstances which arrangement the builder will in every particular case find most expedient to adopt.

If the foundations are 2 bricks thick, the superstructure $1\frac{1}{2}$ bricks thick, the arrangement must be modified. A cross section of such a wall is shown in *Fig.* 10: and for the superstructure the bond of each alternate course may be as in *Figs.* 6 and 7, or as in *Figs. 8 and 9, previously described.*

Fig. 10.



For the thicker foundation courses, the arrangement shown in *Figs.* 11 and 12 may be adopted: where closers at the corner are so placed as to preserve the bond and prevent the ver-

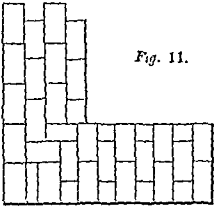


Fig. 11.

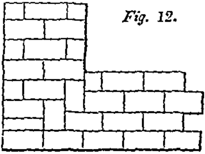


Fig. 12.

tical joints being continuous. Here in each course *one-eighth* of the bricks are *half-bricks*, enabling broken bricks to be utilized. In this arrange-

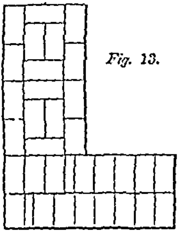


Fig. 13.

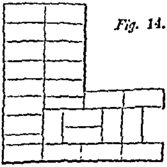


Fig. 14.

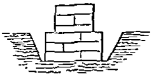
ment each stretcher course has three continuous parallel longitudinal joints

throughout its length: but there is no continuous longitudinal joint in the header course.

If the number of broken bricks is very small, and their use is objected to, the arrangement shown in *Figs.* 13 and 14 can be adopted, where no half-bricks occur except at the corner of each course or closer. Here the continuous longitudinal joints are reduced to two in the stretcher course but one such joint is introduced into the header course. The latter arrangement, as having fewer joints, is the strongest. The stretcher course is not in fact a true case of English bond, but includes a *Flemish* bond, one-brick, course between two centre face-line of stretchers.

325. *Flemish bond.*—This second mode of bonding brickwork, which may be supposed to have arisen from the appearance of the ends of a wall according to the former mode of arrangement (*see e* and *f*, *Fig.* 2, *Plate* XLIV.), instead of placing the bricks in alternate courses of headers and stretchers, places headers and stretchers alternately in the same course, *Fig.* 3. The plans below this at *c* and *d* are of two courses of a fourteen inch wall, with their bond, showing in what manner the joints are broken in the wall horizontally as well as vertically on its face. This is called Flemish bond. Closers are used equally in English and Flemish bond, in the same manner, and for the same purpose; half bricks also will occur in both, but what has been said with reference to the use of them in the former, applies even with more force to the latter, for they are more frequent in Flemish than in English, and its transverse tie is thereby rendered less strong. Their occurrence is a disadvantage which every care should be taken to obviate. The arrangement of the joints, however, in Flemish bond, presenting a neater appearance than that of English bond, it is generally preferred for external walls when their outer faces are not to be covered with plaster; but English bond is preferred by some on the score of greater strength due to a better transverse tie. Other deny this superior strength on the part of English bond, objecting to the continuity of the longitudinal joints in this system: and claim for Flemish bond a more extended longitudinal bond, a matter of importance in distributing the weight of any portion of a wall over a great length of base in unsound or unequal ground. It will be observed on referring to *Plate* XLIV., that in a wall of 7 courses, any one brick of the upper

Fig. 15.



course is supported in English bond by 7, but in Flemish bond by 10, bricks.

326. The following figures illustrate the arrangement of bricks in the alternate courses of walls built in Flemish bond, and the mode of keeping the bond when one wall meets another at right angles by interchanging the course of header and stretcher.

In the one-brick walls (*Figs.* 16, 17) it will be seen that there are no

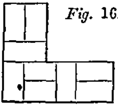


Fig. 16.

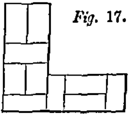


Fig. 17.

continuous longitudinal joints in any course. In one and a half brick walls, (*Figs.* 18, 19) the whole bricks used cover only $\frac{5}{8}$ths the surface of each course; the half bricks being placed in the inside of the wall, where

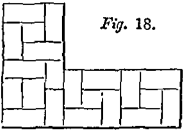


Fig. 18.

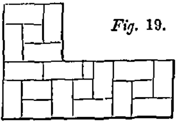


Fig. 19.

if they are truly formed they will aid the cohesion of the mass as far as possible: while by this construction the continuous longitudinal joints are avoided, and a really better bond obtained than can be with the English bond. But two-bricks (*Figs.* 20, 21,) walls can be built yet more solidly,

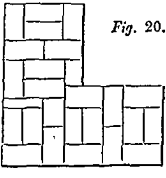


Fig. 20.

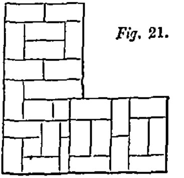


Fig. 21.

half bricks not being necessary: the number of headers however will be double that of the stretchers; and in the centre part of the wall the extent

of longitudinal bond (in which the Flemish bond excels) will be much diminished. If however more stretchers be used, there will be uninterrupted mortar joints dividing the wall perpendicularly and longitudinally, and such an arrangement would be inadmissable.

The above sketches and remarks will enable the reader to plan unaided the arrangements for properly "bonding" walls of any thickness in either of the styles described.

327.—*Thin flat iron*, such as is used for hooping barrels, forms an excellent bond, and is so thin that it may be inserted in the ordinary mortar joints without increasing their thickness. It should be laid along the middle of the wall, or if the wall be thick, in two or more parallel rows at every 2 or 3 feet of its height. If nicked, at intervals, along the edges, it holds better. It is of course, of more use in the foundations and plinth of a building than higher up, as settlements and unequal bearings take their origin in the lower part of a wall, except in cases of very bad workmanship. The cohesion which takes place between iron and hydraulic mortar, whilst there is none between wood and mortar, renders the use of iron, when the cost is not a bar to it, most desirable.

328. Good workmen are well aware of the necessity of attending to the bond, and are ready both to suggest and to receive and practice an improvement; but the generality of workmen are both ignorant of its importance and careless in preserving it, even according to the common modes. Their work should, therefore, be strictly supervised as they proceed with it, for many of the failures which are constantly occurring may be referred to their ignorance or carelessness in this particular.

329. Not second in importance to bonding in brick-work is, that it be perfectly plumb, or vertical, and that every course be perfectly horizontal, or level, both longitudinally and transversely. The lowest course in the footings of a brick wall should be laid with the strictest attention to this latter particular; for the bricks being of equal thickness throughout, the slightest irregularity or incorrectness in that, will be carried into all the courses above it, and can only be rectified by using a greater or less quantity of mortar in one part or another, so that the wall of course yields unequally to the superincumbent weight, as the work goes on, to its great detriment.

330. **Bricklaying.**—In the operation of *Bricklaying*, the workman holds the trowel in his right hand, and with the left he takes up the bricks from the scaffold, and lays them in their places; spooning or shovelling up

mortar from the board with the trowel, he throws it on the course last laid, and with the point strews it over the surface to form a bed for the brick which he is about to set; whatever bulges or projects over the outer edge of the work below is struck off, and being caught on the flat face of the trowel, is put against the side or edge of the last brick laid in the new course. Then taking up a brick, he presses it down in its place until its upper and outer edge comes exactly to the string previously stretched as a guide for that edge of the bricks of the course in hand; and if this be not readily effected by the hand, a slight drawing below with the obtuse point of the edge of the trowel does it, or a tap with the end of the handle both draws it and settles it down farther than the hand can press it. The small quantity of mortar that is pressed out in front, by this operation, being struck off, the joints are neatly drawn by compressing the mortar with the point of the trowel, and thus producing a fine smooth surface,—that is, if the work is to be seen; but if it is to be plastered, the rough face is left that the plastering may the more readily attach itself, and the joint is not drawn at all; the workman proceeds in the same manner with the next brick in advance along the course, or to fill in behind the one he has laid in front to meet the work of his mate on the other side of the same wall.

331. This is the common mode of *laying* bricks. They should not however be merely *laid;* every brick should be rubbed and pressed down in such a manner as to force the slimy matter of the mortar into the pores of the bricks, and so produce absolute adhesion. Moreover it is essentially necessary, that every brick should be soaked in water, before it is laid, otherwise it immediately absorbs the moisture of the mortar, and, its surface being covered with dry dust, and its pores full of air, no adhesion can take place; but if the brick be damp, and the mortar moist, its cementitious matter enters the pores of the brick, so that when the water evaporates, the attachment is complete. To wet the bricks before they were carried on to the scaffold would, by making them heavier, add materially to the labor of carrying: in dry weather they would, moreover, become dry again before they could be used; and for the bricklayer to wet every brick himself would be an unnecessary waste of his time; boys are, therefore, advantageously employed to dip the bricks on the scaffold, and supply them in a damp state to the bricklayer's hand, by whose side, moreover, should be a vessel with water, in which the brick should be allowed to soak before being used. A watering pot with the fine rose to it should also be used to moisten the

upper surface of the last laid course of bricks, preparatory to strewing the mortar over it.* In bricklaying with quick-setting cements these things are of even more importance; indeed, unless the bricks to be set with cement are quite wet, the cement will not attach itself to them at all. The upper surface of all unfinished masonry should at all times be kept well flooded with water.

332. All the walls of a building that are to sustain the same floors and the same roof, should be carried on simultaneously; under no circumstances should more be done in one part than can be reached from the same scaffold, until all the walls are brought up to the same height; and whenever from any cause one part of the wall is in advance of the rest, the ends of the part first built should be racked back, and not carried up vertically with merely the toothing necessary for the bond.

333. Scaffolding.—In ordinary practice, bricklayers' scaffolds are carried up with the walls, and are made to rest on them. The walls having been built up as high as they can be conveniently from the ground, a row of poles is planted, which vary in height from thirty to forty and even fifty feet, parallel to and at a distance of about four feet six inches from the walls, and from twelve to fourteen feet apart. To these, which are called, *standards*, are attached, horizontally, by means of ropes, other poles called *ledgers*, with their upper surface on a level with the highest course of the wall yet laid; on the ledgers and wall, short transverse poles called *putlogs* or *putlocks* are laid as joists to carry the floor of scaffold boards. These putlocks are placed about six or seven feet apart, according to the length and strength of the scaffold boards; and the ends which rest on the walls are carefully laid on the middle of a stretcher, so as to occupy the place of a header brick, which is inserted when the scaffolds are struck, after the work is finished. Indian masons very frequently build the putlocks in, instead of leaving out a brick for their insertion, and in taking them out, when done with, necessarily injure the wall. On the floor of the scaffold thus formed, the bricklayer stands, and the materials are brought to him by laborers, in hods, from the ground below, or they are hoisted up in baskets and buckets by means of a pulley wheel and rope. The mortar is placed on ledged boards of about three feet square, placed at convenient distances along the scaffold: and the bricks are strewn on the scaffold between the mortar boards, leaving a clear way against the wall for the

* The ordinary substitute for this in India is a small earthenware vessel with a spout to it, called a *gumlah*.

workmen to move along unobstructedly. The workman then recommences the operation of bricklaying, beginning at the extreme left of his course, and advancing to the right until he reaches the angle or quoin in that direction, or the place where his fellow-workman on the same side may have begun.

Thus he goes on with course after course, until the wall is as high as he can conveniently reach from that scaffold, when another ledger is tied to the poles, another row of putlocks laid, and the boards are removed up to the new level. The ledgers and most of the putlocks, however, remain to give steadiness to the temporary structure; and so on to the full height of the wall, piecing out the poles by additional lengths as may be required. If a scaffold be very much exposed, and run to a great height it must be braced. This is done by tying poles diagonally across, on the outside of the standards and ledgers, and it may be further secured by tying the ends of some of the putlocks to the ledgers: but an outside scaffold should never be *attached* in any way to the building about which it stands.

A scaffold should never be loaded heavily, as well on account of the work, as of the scaffold itself; for the putlocks resting, as they do, on single bricks, in a green wall, exert an injurious influence on it, which every additional pound weight on the scaffold must necessarily increase. A constant and steady supply of bricks and mortar on the part of the laborers, *without overloading the scaffold at any one time, should be strictly* enforced. It would indeed be an advantage if every scaffold were made with a double row of poles and ledgers, one being on the inside within a few inches of the wall, as is the practice in Stonework. This would obviate the necessity of resting the putlocks on the walls, and do away with putlock holes; but the inner row of poles would be constantly in the way of the bricklayer, who could not either set the bricks or draw the joints so well as if he were unobstructed.

Access is given to scaffolds by ladders, or by inclined planes, made roughly with bamboos or other material at hand.

334. Precaution against settling.—One of the most difficult and important problems in the construction of masonry, is that of preventing unequal settling in parts which require to be connected, but which sustain unequal weights; and the consequent ruptures in the masses arising from this cause. To obviate this difficulty requires on the part of the Engineer no small degree of practical tact. Several precautions must be taken to

diminish as far as practicable the danger from unequal setting. Walls sustaining heavy vertical pressures should be built up uniformly, and with great attention to the bond and correct fitting of the courses. The materials should be uniform in quality and size; and hydraulic mortar thoroughly ground should alone be used; as a further precaution, when practicable, a trial weight may be laid upon the wall whilst the settling is in progress and before the permanent load is laid on.

335. *Racking Back.*—In effecting repairs of masonry when new work is to be connected with old, or when a continuous wall is built up in portions, the ends of each portion should be, what is technically called *racked back*, or built in steps, and the wedge-shaped piece A (*see* figure) forming the junction should not be built till both portions are thoroughly set: no crack will then appear at the junction.

And whenever new work is joined to old, the old should be thoroughly scraped and cleaned.

A

336. The mortar joints of brick masonry should be thin, otherwise there will be cracks in the wall from the unequal resistance to settlement of the bricks and mortar. But to obtain these fine joints it is necessary that the mortar be thoroughly ground and mixed, which is often neglected in this country.

337. Pucka Masonry may be *Plastered* or *Pointed*, or the joints may be drawn very close and fine, so as to show nothing but the brick itself, and this looks better than either, if the bricks are of good uniform color and carefully dressed smooth. But too much chipping not only entails expense but destroys the outer skin of the brick which is best fitted to withstand the effects of the weather. This may be obviated by using none but the best bricks, which have been *table* or *terrace* moulded, and ought to require little or no chipping.

Plastering is generally used to conceal bad work, and as it quickly looks shabby and requires continual repair it ought to be everywhere condemned

for the outsides of buildings. Its application for inside walls will be treated of under the head of BUILDINGS. It may, however, be used to protect kucha pucka masonry, though it would be far better to put the mortar between, than outside, the bricks.

Pointing, if neatly executed, looks well, especially if the bond has been carefully preserved; the joints are raked out, filled with fine white lime, and are drawn straight and square.

338. Hollow Masonry.—Hollow brick walls are now extensively used in *buildings* in England. The bricks themselves may be made hollow, or solid bricks are used, but so arranged as to leave hollows between them. The advantages of this method of construction are economy, lightness, and freedom from damp; and no doubt it would secure in this country greater coolness for the interiors of buildings, whilst the hollow spaces might be used, as they are in English buildings, for purposes of ventilation. At present the solid brick walls employed become so thoroughly heated during the day that they continue to radiate heat at night, so that the temperature of a Barrack in the Upper Provinces is often higher at night than in the day. Were a stratum of air interposed between the outer and inner face of the walls, the heat would doubtless be much reduced.

In *Plate* No. XLV. are shown two descriptions of hollow walls, one made with common bricks, the other requiring the outer bricks to be specially moulded. It is evident that in such walls the greatest attention should be paid to the bond, and none but the best materials should be employed.

339. Kucha Pucka Masonry is commonly used in India where lime is scarce and dear, and economy is an object, or in the case of temporary buildings. The bricks should be sound and well burnt, and laid with strict attention to the bond. The mud mortar should be neither too clayey nor too sandy, and should be mixed with a little chopped straw and cow-dung, and well worked up.

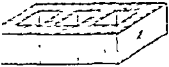
340. Kucha Masonry of sun-dried bricks cemented with mud, is also occasionally used for out-houses, or for the interior walls of larger buildings. The bricks should be made of the best brick earth, very carefully dried before being used, and laid with a proper bond. Masonry of this kind is exposed to danger from its small resistance to crushing, and hence should never be subjected to a heavy weight; and still more to risk from water penetrating into it, which would bring the whole mass down. It should, therefore, be carefully protected from such contact by masonry

BRICK-WORK IN HOLLOW WALLS

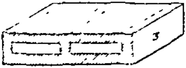
HOLLOW WALLS WITH SPECIALLY MOULDED BRICKS

Clayton's Pattern.

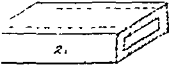
Ayre's Brick.



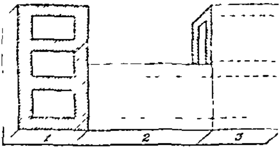
Header Brick



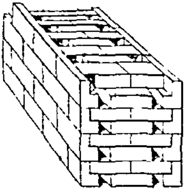
Stretcher Brick



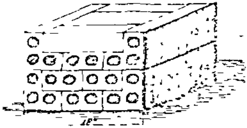
Bricks as they are laid



Another Pattern

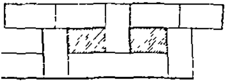


Roberts Pattern

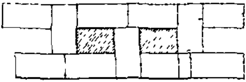


HOLLOW WALLS WITH COMMON BRICKS.

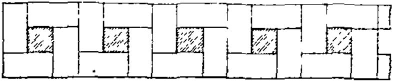
1st Course

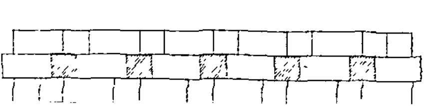


2nd Course



Another arrangement.





of burnt brick (as on the tops of walls), and should never be used in foundations.

341. Kucha Walls of mud alone, are also very frequent,—constructed sometimes of clay, not made into bricks, but in large lumps laid on one another in a soft moist state, and so adhering together as to form, when dry, one compact mass; or stiff mud, built in layers, well pressed down with the hand, or by hands and feet if the wall is thick enough; in dry weather the sun soon bakes each layer or course, sufficiently to allow of the wall being added to. Walls so built generally taper somewhat, and are apt to have vertical fissures. When completed, they may be cut and pared at the base, trimmed and plastered with clayey earth mixed with *bhoosa*, or chopped straw, which may also be mixed with advantage in the mud wherewith the wall is built. It is wonderful how much exposure to the rain, such walls, when carefully built in dry weather, with suitable earth, will stand.

342. Pisé Walls.—There is another description of earthen-wall-work called *Pisé*. The prepared clay, with a very small admixture or sprinkling of water, or even quite dry, is rammed hard between two parallel rows of board, fixed at the distance apart of the proposed thickness of wall. The mass becomes firm and hard, and the retaining boards are removed. This construction is expensive and has little advantage over ordinary mud walls, built under favorable circumstances, except that its faces are perpendicular.

343. The following Brick-work Specifications used in the Allahabad Circle of Public Works will be found useful:—

First class brick-work will consist of first class bricks laid in cement; the bricks to be of uniform size, thoroughly and equally burnt, of a deep red or copper color, not

course to be thoroughly grouted.

No batts (broken bits) to be used in the brick-work.

No joint to be more than three-eighths of an inch in thickness.

Every brick to be saturated with water before it is put into the work.

When the brick-work is not to be plastered, bricks of a uniform color are to be selected for all face-work.

The tops of unfinished masonry to be kept at al times flooded with water.

The walls to be carried up regularly in all case where the nature of the work will permit.

In all cases, returns, buttresses, counterforts, &c., are to be built up, course by course, with, and carefully bonded into, their main walls. These are never to be joggled on afterwards.

Where the masonry in one section of a building cannot be carried up in even courses, the break is to be left in regular steps, so that the new work to be added may be built on over the old.

The *Mortar* to be composed of kunkur or stone lime, mixed with soorkee or sand, in such proportion as the Executive Engineer may direct, according to the quality of the lime to be used. If necessary, a proportion of stone lime will be added to mortar made of kunkur lime. The mortar will be thoroughly ground and mixed under edge stones.

The kunkur lime may be burnt in kilns with charcoal or wood, or clamps with ooplah, as the Executive Engineer may direct.

The soorkee is to be finely pounded, made from well-burnt bricks or from properly tempered and approved clay or loam, worked into lumps with the hand, and well burnt.

If sand be used, it is to be sharp, coarse-grained river sand, clean and free from clay or earth.

Not less than 24 cubic feet of mortar (dry) to be used to the 100 cubic feet of masonry, when the bricks measure $9'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$. More will be required if the bricks be smaller, less if the bricks be larger, but no alteration of the rate will be made on this account.

Second class brick-work will be executed of similar workmanship generally as first class, but with second class bricks, viz., of uniform size, burnt throughout of a light red—not straw color.

No joints to be more than half an inch in thickness.

Mortar not to be ground under edge stones, but mixed in a trough.

This work will, with very few exceptions, be plastered.

Third class brick-work will be executed with bricks similar to those described for second class, but laid in mud.

The execution of the work in bond and other details to be as for second class brick-work.

The mud to be well tempered—if very plastic, a proportion of sand to be added. To be worked down with water till it is perfectly free from lumps and of the consis-

into three classes. *First class bricks* will be of uniform size and color, thoroughly and equally burnt throughout, not vitrified, having a clear ring, well-shaped, square and true, without flaw or crack.

Second class bricks will comprise those which are not uniform in size or color, which are burnt unequally in parts, or which are a little vitrified or unevenly shaped; but they must all be well burnt and have a clear ring, and must be free from cracks or flaws.

Well-shaped bricks which are slightly under burnt and bricks which have been much fused will be classed as *third class*, and will be set aside for temporary buildings or out-offices.

To ensure none but good materials being put into the work, all bricks shall be stacked at the site of building in regular backs from 1½ feet to 2½ feet in thickness, and shall be carefully packed by hand. Stacking in large loose heaps will not be allowed.

All lime supplied by a contractor shall be examined and passed by the officer or subordinate in charge before it is slaked.

Bricks shall be soaked in tanks or tubs for at least 24 hours before being used. All stones shall be thoroughly flushed with water before being set. As the work proceeds, it will be kept thoroughly wetted until the mortar has set firm and hard. On closing work for the day, small mounds of mortar 1½ inch high will be set all round the upper surface of the masonry and filled with water, which will be left to soak in during the night. On Sundays and holidays they must be kept continuously filled with water.

Where practicable, the whole of the masonry in any structure will be carried up at one uniform level throughout, but where breaks are unavoidable they will be made in good long steps, so as to prevent cracks arising between the new and old work. All cross walls and junctions will be carefully bonded together.

Church towers and similar structures rising to any considerable height above the buildings to which they are attached will be constructed independently of it, and shall not be bonded in with its walls.

Chimneys and ventilating shafts shall be carried up straight and smooth, and will be plastered internally as the work proceeds, care being taken to leave no projections or other irregularities to interfere with the up draught. Chimneys will be carefully gathered in above the fire-place with an easy sweep.

The foundations of all walls shall be spread out in regular steps, so as to give them a firm footing upon the soil beneath.

The exterior surface of all vaults under roofs or floors, also [in bridges and culverts] the extrados of the arches and the top of the backing, shall be staunched with a covering of fine concrete of such thickness as shall be directed. In large bridges, or wherever considered necessary, a coat of asphalte or well boiled coal tar will be laid over the staunching.

[illegible] shall be [illegible]. All horizontal joints shall be straight, [illegible] angles to the face and not horizontally. Battering rules, levels, and plumb rules of the English pattern shall be used as much as possible by masons in lieu of the untrustworthy native implements.

First class brick-work will be composed of first class bricks set in lime mortar; *second class work* will be composed of second class bricks also set in lime mortar.

All bricks shall be thoroughly flushed in mortar, and shall be grouted at every fourth course. In first class work no joint shall exceed $\frac{3}{8}$th inch in thickness, in second class work $\frac{1}{2}$th inch will be the maximum.

The bond used will be English or Flemish, at the option of the Executive Engineer, and shall be carried throughout the wall. No bats shall be used in the work, and no more half bricks than are necessary to complete the bond.

The best bricks of their respective classes will be selected for arches, and shall be properly gauged. All joints shall be truly summered; the bricks shall be set with as close joint as possible, and the rings shall be carefully bonded into each other.

All string courses, cornices, and mouldings will be set straight and true, with as fine joints as possible.

Brick-work in mud will be of third class bricks set in mud mortar. When these bricks are laid in lime mortar it will be designated *3rd class brick-work.* The mortar need not be ground in a mill. The bricks will be laid with as much attention to bond as is possible.

Earth for mud plaster and for leeping shall be sifted fine, and will then be thrown into a pit with a small quantity of chopped bhoosa and cow-dung; the whole will be well mixed and flooded with water, and it will then be left for at least three weeks or until the vegetable matter is fairly rotted down. Kucha plaster will always be floated on in thin coats, successive ones being added if a greater thickness is desired.

CHAPTER XVIII.

ARCHING.

345. A MASONRY Arch is an assemblage of wedge-shaped stones, (or of substitutes for them, such as bricks,)—called *Voussoirs*,—covering a space, and supported intermediately by their mutual pressure on each other caused by gravity, and ultimately by their pressure against the solid body from which they spring on either hand, whether this be the firm ground, a mass of masonry called an *abutment* or *buttress*, or the counter-thrust of a similar arch resting on the same pier, or point of vertical support.

The under side of an arch is called the *Intrados* or *Soffit;* the former term being used when large arches, like those of a bridge, are spoken of, and the latter for small arches, such as usually occur in buildings. The outside of an arch is called the *Extrados* or *back*. The two lowest extremities of an arch are called its *Springings* or *springing lines*. A line extending from the springing line on one side of an arch to the springing line on the opposite side, is called the *Span* of the arch. The *Crown* of the arch is the part most remote from the springing line, and the parts of the arch for a certain distance up each side from the springing lines are called the *Haunches*. The *Spandrils* are the spaces contained between the extrados and a horizontal line from the crown.

346. Curve of Equilibrium.—If the arch stones had polished surfaces they would slip on each other, unless the direction of the pressure between each pair of voussoirs was exactly perpendicular to the direction of the joint between them; and as the direction and amount of pressure caused by each voussoir of an arch, depend on its weight added to that carried by it, and on the form of the arch, the lines of directions of the pressure throughout the arch form a polygon, whose sides should cut every joint at right angles. This polygon, by assuming the stones to be infinitely small compared with the span of the arch, becomes a curve called the *Curve of Equilibrium*. This curve can in all possible cases be deter-

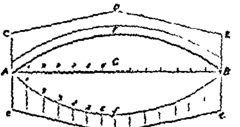
mined by calculations, which however, except in the simplest cases, are abstruse, and the reader is referred to Moseley's and Weisbach's Treatises on Mechanics, for the best theories on the equilibration of arches.

Experimentally, however, an equilibrated arch, to suit any conditions, may easily be drawn. A chain suspended from two points at a distance from each other, and allowed to hang freely to the depth due to its length, will evidently be in equilibrium; that is, its parts will so dispose themselves that none has a tendency to push the other aside; or in other words, the vertical force of each link being supported by the hooks to which the chain is suspended, the horizontal thrust of each is met by the equal and contrary force of the links on each side of it. If these forces were unequal, motion would ensue; as soon therefore as the chain is stationary, the balance or equilibrium of its parts is established.

The festoon thus formed is an arch reversed, if the points of suspension represent the abutments of the arch, which in the former are drawn together, in the latter thrust asunder, with equal force; supposing the weight and depth of the festoon to be equal to the weight and rise of the ring of arch stones.

If the chain is composed of links of equal length and weight, the festoon will form a curve called the *catenary*. By increasing the weight of the links towards the points of suspension the festoon will become flatter, and the form will thus be adapted to arches of bridges, whose haunches are built up to carry a level, or nearly level roadway.

Now to ascertain the form of an arch which shall have a span AB and a rise FG, with a roadway following the line CDE. Let the figure ACDEB be inverted, so as to form a figure *AcdeB* Let a very flexible chain with links of equal length and of uniform thickness be suspended from the points A and B, and let the chain be of such a length that its lower point will hang a little below *f*, corresponding to F. Divide AB into a number of equal parts in the points



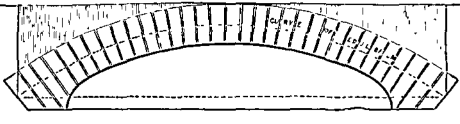
1, 2, 3, &c, and draw vertical lines cutting the chain in the corresponding points 1, 2, 3, &c. Now take pieces of a similar chain and hang

them at the points 1, 2, 3, &c., of the chain AfB, which will alter the form of the curve. Cut or trim these pieces of chain till their lower ends all coincide with the inverted roadway *cde*. The greater lengths which are hung on or near A and B will pull down the points to which they are attached, and cause the middle point f, which is less loaded, to rise a little, and thus bring it to the height fixed upon for the rise of the arch.

An arch built in this form will be in perfect equilibrium, if the proportion between the weight of the ring of arch stones of a depth proportional to the horizontal thrust of the arch, and the weight of roadway, spandril walls, &c., carried by it, is the same as that between the chain AfB and the bits of chain suspended by it. Should this proportion be the same or nearly so, the curve is the one required; if otherwise the number or the weight of the suspended pieces of chain must be added to or subtracted from, till the desired proportion is obtained. The load over a bridge arch is, in consequence of the plan of having hollows in the spandrils, not distributed exactly in proportion to the height of the wall over each separate arch stone, and the specific gravity of the mass over the haunches being thus less than over the crown, an additional adjustment of the suspended bits of chain is thereby indicated. The arch of equilibrium is formed to see whether, when applied to the form of arch chosen, it lies everywhere well within the depth of the arch stones which compose it.

347. An arch built exactly on the true curve of equilibrium would

LINE OF ROADWAY.



stand, although no mortar was used in its construction, and even if the voussoirs were highly polished on their bearing surfaces.

In practice, however, the extent of the surfaces of the arch joints, their friction, and the tenacity of the mortar between them render a departure from the true curve of equilibrium in the form of an arch, especially of a loaded one, as that of a bridge, unimportant within certain limits; still,

in order to determine those limits, and in heavy arches to avoid any approach to the degree of compression which the materials used are incapable of enduring, the best form should be known, as there will always be an economy of materials disposed in such forms, in ignorance of which safety, if attained, can be so only by waste; and it must always be remembered that in buildings intended to be permanent, allowance must be made in constructions of brick-work and masonry, for the effect of concussion caused by storm, earthquake, or floods, as in constructions of wood and metals for effect of decay and rust.

It is, therefore, requisite that the curve of equilibrium of an arch should be contained between the lines of its upper and lower surfaces, called its extrados and intrados, and not be allowed to approach too near to either; otherwise, the thrust might, if brought too near the edges of the voussoirs, splinter them, and thus changing the form of the arch and bringing fresh points under pressure, perhaps crush them in detail.

348. The effect of the cohesion of the mortar in arches, is to cause the breaking up of an arch whose equilibrium is defective, into three or four masses which may be considered as the sides of a polygon, whose angles are at those points of the extrados and intrados where they are cut by the curve of equilibrium; motion may take place about these points, unless the thrust in the direction of the sides of the polygon is met both in the piers and in the points where the arch has a tendency to open outwards, by a sufficient weight to counteract it.

It will be seen at once, therefore, that quite different forms are required for weighted and unweighted arches; the former are as in bridges the latter in roofs. For instance, it has been found that an unloaded semi-circular arch whose extrados is parallel to the intrados, with a thickness less than 1-16th of its span, will give way by the rising of its haunches; this relative thickness not containing in it a curve of equilibrium under the given conditions.

It is evident that the weight thrown on the haunches of a bridge in order to bring the roadway to a level, will counteract this tendency of semi-circular arches to bulge out at these points; the remedy, however, may be carried too far, as was proved by an enterprising Welshman, named Edwards, in 1751, who built a bridge of a single segmental arch of 140 feet span, and 35 feet rise, over the river Taaf, but filling in the haunches with solid masonry, the crown of the arch was forced up and it

fell. The bridge was rebuilt with hollows left in the haunches, and is, we believe, still standing.

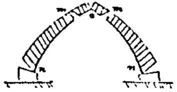
349. From observations of the manner in which large cylindrical arches settle, and experiments made on a small scale, it appears that in all cases of arches where the rise is not greater than the half-span, they yield by the crown of the arch falling inwards, and thrusting the lower portions outwards, presenting five *joints of rupture*; one at the key-stone, one on each side of it, which limit the portions that fall inwards, and one on each side near the springing lines, which limit the parts thrust outwards.

Fig. 1

The figure (1) in the margin represents the manner in which such arches yield by rupture: *o*, joint of rupture at the key-stone: *mm*, joints of rupture below the key-stone: *nn*, joints of rupture at springing lines.

In pointed arches or those in which the rise is greater than the half-span, the tendency to yield is different; here the lower parts fall inwards, and thrust the parts near the crown upwards and outwards.

Fig. 2



The marginal figure (2) represents the manner in which pointed arches yield; *mn* falling inwards and *mo* outwards.

350. Calculation of Thrust.—From this movement in arches, a pressure arises against the key-stone, termed the *horizontal thrust* of the arch, the tendency of which is to crush the stone at the key, and to overturn the abutments of the arch, causing them to rotate about the exterior edge of some one of their horizontal joints.

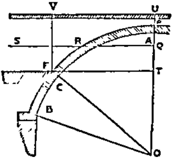
The joints of rupture below the key-stone vary in arches of different forms, and in the same arch differently loaded. From experiments, it appears, that in semi-circular arches, the joints in question make an angle of about 27° with the horizon; in segmental arches of arcs less than 120°, they are at the springing lines; and in oval arches of three centres, they are found at about 45° from the springing line, measured on the small arc which forms the extremity of the curve.

The calculation of the points of rupture, the consequent horizontal thrust, and its effect in crushing the stone at the key, and in overturning

the abutment, are problems of considerable mathematical intricacy, which have been solved by a number of writers on the theory of the equilibrium of arches, and tables for effecting the necessary numerical calculation have been drawn up from their results to abridge the labor in each case. The following formula is given by Rankine, as sufficiently accurate for practically finding the horizontal thrust of the arch, from which the necessary thickness of the abutment wall, or buttress, to resist this thrust can be determined :—

Circular Arch not less than a Quadrant.—The horizontal thrust is nearly equal to the weight supported between the crown and that part of the soffit whose inclination is 45°.

Thus, in figure, let ACB represent one-half of a circular arch, O being the centre of the intrados and OA its radius, $= r$; let OP $= r'$, PU $= c$; UV being the horizontal platform. Draw OCF, making the angle AOC $= 45°$ with the vertical; then the horizontal thrust of the arch will be nearly equal to the weight of the mass ACFVU, which lies between the joint CF and the crown. The point F is that up to whose level it is advisable to build the backing solid, or at all events, to bond and joint it in such a manner that it shall be capable of transmitting a horizontal thrust. Draw FT horizontal; then PT $=$ ·7071 OP.



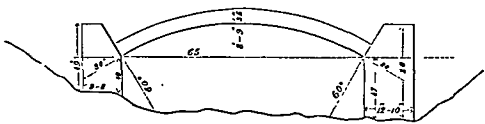
Circular Arch less than a Quadrant.—Take the weight of a half-arch with its load, and multiply by the co-tangent of the inclination of the intrados to the horizon at the springing.

This thrust when applied at the top of an abutment will act with the greatest force at its base, or at the full extent of the lever whose length is the height of the abutment; the resistance will consist of the abutment calculated by multiplying the content by the weight of the material, and by the length of the leverage, calculated from the point over which its centre of gravity must be turned, added to the weight of the half arch resting on the abutment, acting at the point from which it springs, and to the cohesion of the mortar joint which must give way before the mass can begin to move.

351. This method of determining the thickness of an abutment to

resist the effort of an arch to turn it over, will be best illustrated by an example.

The abutment arch of the Hutcheson Bridge, Glasgow, built by Mr. R. Stevenson, is a segment of 60° of a circle, the radius and span being each 65 feet. The line of thrust, which is tangent to the curve at the springing, forms therefore an angle of 30° with the horizon. The thickness of the arch is everywhere $3\frac{1}{2}$ feet, the height of the springing line is 17 feet, the abutment is carried up solid to a mean height of 26 feet.



To find the thrust of this arch, it will be requisite to allow for the weight of the roadway and occasional loads passing over it, and when the material is stone, $1\frac{1}{2}$ feet added to the thickness of the arch may be taken to cover all; the arch then averages 5 feet in thickness, and the length of the half arch 35 feet nearly. A cubic foot of masonry may be taken at 120 lbs., and in making the calculation of the thrust of the arch and the resistance of the abutment, it will be sufficient to take one running foot in length for each

The weight of the half arch then will be $= 5 \times 35 \times 120 \times 1 = 21{,}000$ lbs., and this weight multiplied by the cot of 30° will give the *horizontal* thrust of the arch, and this thrust acts upon the abutment at the springing line, and therefore with a leverage of 17 feet in this case.

The moment of the arch then, tending to overturn the abutment will be $= 21{,}000 \times \sqrt{3} \times 17$. The resistance the abutment can offer to this will be, first, its own weight multiplied by half its thickness, second, the strength of the abutment against rupture at the mortar joint; and third, the effect of the weight of the arch itself in preventing the abutment from turning over, that is, from its resting upon the inner edge of the abutment.

If we take 1000 lbs. as the cohesive strength of the mortar joint per superficial foot and the weight of the masonry 120 lbs. per cubic foot, as in the arch; also if x represent the thickness of the abutment, then the resistance of the abutment will be as follows:—

(i). Resistance due to its own weight $= 26 \times x \times 1 \times 120 \times \frac{x}{2} = 1560\,x^2$.

(ii). Resistance due to mortar joint $= 1000 \times x \times \frac{x}{2} \qquad = 500\,x^2$.

(iii). Resistance due to arch, ... $= 21000\,x$.

Then, if these be equated with the moment of the arch, we have

$$2060\,x^2 + 21000\,x = 21000 \times \sqrt{3} \times 17.$$

And solving this equation, we get $x = 12{\cdot}9$ feet.

This equation of equilibrium, as it is called, may be put in an algebraic form as

follows, supposing the arch not to exceed a quadrant, and the back and front of the abutment to be perpendicular.

Let W = the weight of the half arch with its superincumbent load of backing and roadway, &c.

a = the angle subtended by the half arch, or, which is the same thing, the angle of inclination of the tangent to the curve at the springing line.

w = weight per cubic foot of the masonry of the abutment.

h = height of abutment to springing line.

h_1 = mean height of abutment.

c = cohesive strength of mortar joint per superficial foot.

h = horizontal thrust of arch.

Then $H = W \cot a$, and the moment of the arch $= h\,W \cot a$, and putting x for the thickness of the abutment as before, the equation of equilibrium will be

$$\left(\frac{h_1\,w + c}{2}\right) x^2 + W\,x = h\,W \cot a.$$

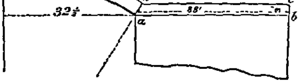
In the example given above, suppose the mean height of the abutment to be only 19 feet, and the arch springing from 10 feet.

The moment of the arch will then be $= 21000 \times \sqrt{3} \times 10$, and the resistance will be $1140x^2 + 500x^2 + 21000\,x$, or the equation will be

$1640x^2 + 21000x = 21000 \times \sqrt{3} \times 10$, and solving this equation

$x = 9{\cdot}8$, or 3 feet less than in the former case.

If there were no cohesion between the stones or bricks forming an abutment, the horizontal thrust would cause them to slide on each other at the joints; thus in the accompanying figure, the thrust of the arch f, would be resisted only by the friction in the joint ab, which would be equal only to about seven-tenths of the weight of the mass $abcd$, $\cdot 7$ being the coefficient of friction of stone or brick. If $abcd$ be taken as a rectangle, bc 3 feet, suppose, and 120 lbs. as the weight per cubic foot as before, also let x represent the width ab; then the weight of the mass $abcd$ will be $= 3 \times 120 \times x = 360\,x$. To this add the weight of the half arch resting upon it, or 21000 lbs, then the whole resistance of friction will be $= \cdot 7\,(360x + 21000) = 252x + 14700$. Equating this with the horizontal thrust of the arch as found before, we have $252x + 14700 = 21000\sqrt{3}$, whence



$x = 86$ feet.

The cohesion of common mortar, according to Rondelet, is from 2160 to 4320 lbs. per superficial foot, but according to some experiments made recently in connection with the masonry forts in the Bombay Harbour,* it was found to average only 2362 lbs. for the best, and 1270 lbs. for worst, class of mortars.

Referring again to the last calculation, when the abutment is supposed to yield by

* "Professional Papers on Indian Engineering (First Series)," for November 1868.

sliding, there would, in practice always be mortar between the layers of masonry in the abutment, and the resistance of the mortar joint along the line *ab* would offer the principal resistance to the thrust of the arch In the above case, if we take 2000 lbs as the cohesive strength per superficial foot of the mortar, and also assume the resistance to detrusion to be the same as the cohesion, the strength or resistance of the mortar joint will be $= 2000\ x$, and equating this with the thrust of the arch, we have

$$2000\ x = 21000\ \sqrt{3}$$
$$\therefore\ = 18\ 18 \text{ feet.}$$

It appears from this, that it will be necessary with abutments of small height to calculate the thickness both for overturning and detrusion, and to take whichever is the greater as the minimum thickness.

In considering the case of detrusion, it is evident that an abutment which is likely to be tested in this way should be allowed to set thoroughly before the arch is turned or at any rate before the centering is removed.

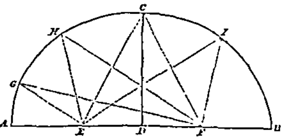
352. In the above, and all similar calculations, it must be remembered that the thickness of the abutment thus found is the *minimum* thickness absolutely required to resist the thrust. But in actual practice an addition of about one-eighth should be made to the calculated mass of the abutment, to ensure safety.

In Elliptic arches, the portion of the arch immediately above the skewback should be taken to form part of the abutment, and the thrust may be calculated, as before, by treating the curve as a series of circular segments.

More will be said on Abutments under the Section BRIDGES.

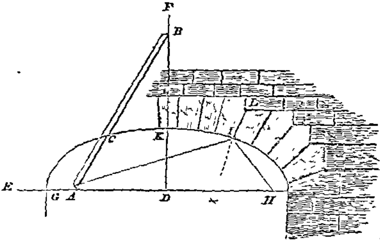
353. Form of Arches.—Arches may be Semi-Circular, Segmental, Semi-Elliptical, or Pointed.

Semi-Elliptical Arch.—To set out a semi-elliptical arch, draw a line AB equal to the span or transverse axis of the ellipse. On this at right angles draw CD equal to the rise (which will be the semi-conjugate). Then from the vertex C, with radius AD or DB equal to half the span, describe an arc intersecting AB in E and F. These two points will be the foci of the ellipse. If two nails or pegs be fixed in the foci, and a line attached to them equal in length to AB, then the curve traced by a nail keeping this line stretched, will be the ellipse required;



the lines EGF, EHF, ECF, EIF, &c., being all equal to the span AB, and to each other.

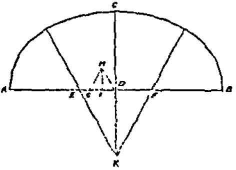
354. An elliptic arch may also be described by continued motion in the following manner:—On a straight bar AB (*see* figure), if AC be made equal to the height of the arch, and CB equal to half the span, then if the end of A be moved along a straight edge ED, while the point B moves along another straight edge FD perpendicular to ED, the point C will describe an elliptic quadrant. If the bar be made



to move on rollers, an arch of considerable size may be accurately described in this way, when a trammel would become unmanageable. To find the direction of the joints, with a radius equal to half the span, from *the point K (see figure), as a centre, describe the arc GH, which deter*mines the points G, H, called the foci. Let it now be required to draw a joint at I, join IG and IH, draw LI to bisect the angle GIH, and it is the *joint required.*

355. *Many centered Circular arch.*—Curves formed of arcs of circles of unequal radii, and similar in appearance to the ellipse, are sometimes adopted for the arches of bridges; with the same rise and span, they may be constructed to give a greater waterway, and in stone bridges they have been preferred by practical stone cutters, but in brick bridges they have no advantage in simplicity over elliptical arches. They may be described with three or a greater odd number of centres. The number of centres will depend on the relation between the span and rise; when the latter is one-third, or a greater fractional part of the former, three centres may be used, but if the rise is less than one-third of the span, then five, or a greater odd number must be taken. In practice, it will be found troublesome to describe arcs from a large number of centres, nor indeed will occasion be found for

using curves of this description. The following is a method of describing a



curve composed of three arcs, each of 60°. Let AB (*see* figure) represent the span, and CD the rise, take DG = AD − DC, and on it describe an equilateral triangle DGH, let fall the perpendicular HI and take IE = HI. In the same way the point F is found. On EF describe the equilateral triangle EFK, then E, F and K, will be the centres required.

If the oval arch rise one-third, bisect the *half spans AD and DB* (*see*

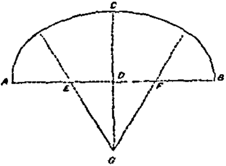
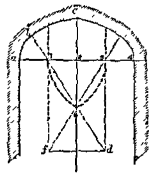


figure) in the points E and F, and produce versed sine CD to G making DG = DC, then E, F, and G, will be the three centres with which the curve may be described. In setting out arches, the practical difficulty arises from the elasticity of string. Instead of a string, soft wire, about a tenth of an inch in diameter, should be used. When the radius does not exceed 12 or 15 feet, a slip of wood may be used with a nail at each end.

356. *Pointed Arches.*—The next figure illustrates the mode of describing the usual four-centered Tudor arch, which



is generally adopted as a very graceful form. Set off *a*4 equal to the width of the arch, and divide it into four parts, as *a*1, 12, 23, and 34. Then, with 13 as a radius on the points 1 and 3, describe the arcs 1*e* and 3*e*. Draw lines through 1*e* and 3*e*, after which, rule perpendicular lines lines through 1 and 3, cutting the lines 1*e* and 3*e* in *d* and *f*. This done, with 1*a* as a radius on the point 1, describe the arc *ab*; then with the radius *bd*, draw the remainder of the arch *bc*. The other side of the arch is completed by a similar process.

357. *Plate* XLVI., contains four examples of Gothic arches of various periods, elucidating some of the principles which may be adopted in designing similar arches, and the leading feature to be observed in the setting-out and working of them.

Fig. 1 is an Early English arch, struck from two centres, and having three surfaces of mouldings. The width of the opening is, in this case, divided into five parts, the two points, 2 and 3, level with the top of the capitals, being the centres from which the arch is described. In this specimen, the outermost and innermost shafts are worked in the courses, while the shaft between them is of long stones detached from the jamb; this latter kind of column is a very common and pleasing feature, in this, and the early part of the succeeding style.

Fig. 2 is a very beautiful trefoil arch of the early part of the 14th century: the springing is a few inches above the capitals. The span from 0 to 11 is divided into eleven equal parts; from the divisions 2, 9, as a base erect an equilateral triangle, and upon the divisions 2, 3, 4, and 7, 8, 9, as bases, the small equilateral triangles 2, 3°, 4, and 7, 8°, 9, the extreme angles of which give the points from which the curves of the arch are drawn. The dotted lines from the centres to the arch represent the mode of drawing the joints, the different planes of which meet at the mitre of the mouldings in the spandril—a feature which should always be preserved in order to make sound workmanship.

Fig. 3 represents a foliated arch with double featherings, viz., featherings or cusps on two different planes. The same general principles are observed in describing these arches, as may be seen by consulting the *Plate*; but the featherings in ancient examples are greatly varied in forms and treatment. *This design is of the Early Decorated period, in which* the principal spandrils are carved, and sometimes both the principal and the minor ones; but in later examples they are ornamented with pierced tracery. The radiating joints must be carefully maintained, care being taken to work the carving in single stones as far as possible.

Fig. 4 is a four-centered arch of the perpendicular period. This arch is formed by the space from 0 to 9 (the leading fillet being taken as the guide). This must be divided into nine parts; upon the bases 1, $5\frac{1}{2}$; 8, $3\frac{1}{2}$, describe the inverted equilateral triangles 1, 10, $5\frac{1}{2}$; 8, 11, $3\frac{1}{2}$; and from the points 10, $5\frac{1}{2}$, and 11, $3\frac{1}{2}$, the arch is struck.

358. The mason, in order to put a design into execution, must set

thicknesses of plank nailed together with the grain of the wood crossing; as in the above sketch.

Similar centerings with three or more ribs are applicable to road tunnels, and may be made into lengths of 10½ feet each, the lagging being nailed on to each rib and extending over at least two spaces; the joints, if any, being alternate, so as to hold the whole framework well together. In building the drain or tunnel, the centering is first to be fixed in its proper place, at one end of the work, and the arch is then built over its whole extent. That done, the centre is *struck* (which is the technical expression for releasing and taken down the centering), and it is moved forward very nearly its own length, taking care to leave 3 inches of one of its ends underneath, but in contact with the underside of the portion of arch that has been built. In this new position, it is to be made straight and level, and again fixed; when a second quantity of arch work equal to its length may be built upon it, when it is again struck, advanced, adjusted, and fixed, and is ready for a third length of work; and by this process, a tunnel may be continued any required distance with only one short centering. Two or three centerings of this kind will be found very useful, when a large number of tunnels of the same span are to be built on a new line of road; where, however, wood is dear and carpenters scarce, a solid centering of earth may be formed, by filling in between the side walls, or abutments with rammed earth, and then forming a raised surface of the same to the shape required. This mould is to be removed by digging out, after the tunnel is completed, or so far as completed at any time.

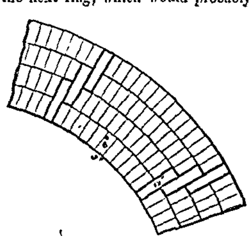
The centerings required for large arches, and the methods used in striking such centres, are treated of under the Section CARPENTRY.

363. Various periods have been laid down as proper to allow between the keying and the uncentering of arches, though it has been generally agreed that immediately after the completion of the arch, the centerings should be slacked a little, so that the bricks may close in and compress the mortar. And certainly this should be done before the facing, spandrel, and outside parapet walls are built upon the arches, because a trifling change of form in the arch may occur by its settlement without imparing its strength, but which might crack and disfigure the external face walls; but if they are not built until the arch has taken its final set, there will be no danger of their being afterwards deranged or disfigured. Arches have been safely uncentered immediately after keying,

are liable to cause the bricks to be broken, or to produce unequal pressure, whereby the regular setting of the arch may be disturbed, its figure distorted, and its strength impaired.

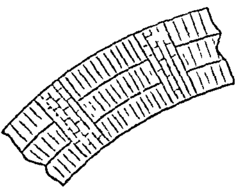
To obviate this inconvenience, arches are generally built in concentric rings one brick, or half-a brick, thick, each ring having the lower edges of its bricks touching each other; thus no great divergence can take place in the joints, and as each ring contains a greater number of bricks than the ring, below it, the arch is more solid.

This method should not be used in arches of more than 30 fee span as there is danger of the concentric rings settling unequally, when the whole pressure might have to be momentarily sustained by a single ring, which would be liable to crush under it, and thus bring the pressure on the next ring, which would probably give way in a similar manner, and the whole arch thus fail.



In small arches, the method of bonding through the concentric rings, which is shown in the marginal figure, is *both effective and* simple, precluding the necessity of extra mortar towards the extrados, and involving no cutting or dressing of the bricks, an evil to be avoided in brick-work wherever it is possible.

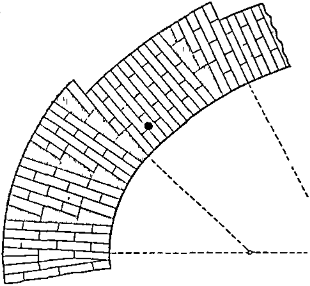
Another plan, which may be adopted (except in very flat segmental arches, in which the length of the extrados and intrados differ but little), is to build the arch in concentric rings, separated at short intervals by blocks of brick-work built as solidly as possible, either with rectangular bricks or with bricks specially moulded with reference to the positions they are to occupy in the arch.



In important structures, however, such as bridges of large span, it is *better to employ the complete bond (as in ordinary wall building)* through

the whole depth of the arch, either using bricks specially moulded, or carefully cutting the ordinary bricks to the proper wedge form.

In this mode of building, each half arch may be considered as a bent wall, whose bed joints are not exactly parallel, but normal to the shorter curved side—the intrados of the arch.



The marginal sketch shows a form of wedge bricks used by Major Forlong, Supdg. Engineer. A string course of wedge bricks is introduced at true calculated distances so as to restore at that point the true radiation of the wedge joint; the intermediate string courses being laid with parallel, not radiating, bed joints.

367. Flat Arches are used instead of wood or stone lintels over square headed windows and doors. They are generally a brick and a half thick, and the bricks should be very carefully cut or moulded to shape and set in the best mortar. They should always have semi-circular or segmental *discharging* arches over them, (*see Plate* XLVII).

368. A Rampant Arch is one whose springings are on different levels. As one impost joint must be oblique to the horizon, care must be taken, if this obliquity be not less than the angle of friction of the stone used, either to cut the impost into steps, or else to use some suitable bond of metal cramps and bolts to prevent disjunction between the arch and abutment.

369. Inverted Arches or Inverts are discharging arches which are built *under* openings—their use being to distribute the superincumbent weight equally over the substructure, or along the foundation, as the case may be. Arches of two half bricks are sufficient for ordinary pur-

poses; in large and heavy works, arches of three half bricks, and even greater, may be judged necessary. Any arc between a quadrant and a semicircle may be used with advantage: but an arc of less than 45° cannot be recommended for the inverted discharging arch under piers. If it should so happen that an old well or cess-pool, that cannot without great inconvenience and expense be filled up with sound walling, or in some other efficient manner, or other irremediably bad place, occur in a foundation, and fall under a pier, the ground being sound on either side of it, a second discharging arch may be formed under the pier and over the unsound part, resting its legs on, or springing from, the inverted arch under the opening, and on the sound ground.

Plate XLVII. shows an elevation and plan of part of the wall surrounding one of the great London Prisons, which was built upon ground over which was deposited artificial soil, varying from 20 to 6 feet deep. By the use of buttresses and inverts, as shown, a great economy of construction was obtained.

370. Underground Arches Tunnels, Culverts.—If the depth of a buried archway, such as a tunnel or culvert, beneath the surface of the ground, is great compared with the height of the archway, the proper form for the line of pressures, which must be within the middle third of the thickness of the arch, is an *Elliptic linear arch*, in which the ratio of the horizontal to the vertical semi-axis is the square root of the ratio of the horizontal to the vertical pressure of the earth; that is to say,

$$\frac{\text{horizontal semi-axis.}}{\text{vertical semi-axis}} = c = \sqrt{\frac{p_y}{p_x}} = \sqrt{\left(\frac{1-\sin\phi}{1+\sin\phi}\right)} \quad \text{.........} \quad (1).$$

ϕ being the angle of repose.

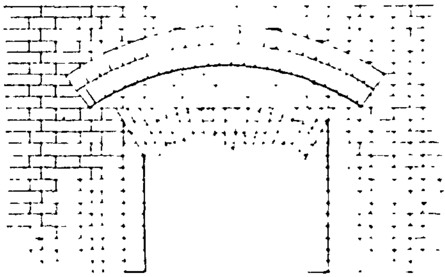
If the earth is firm, and little liable to be disturbed, the proportion of the half span, (or horizontal semi-axis,) to the rise, (or vertical semi-axis,) may be made *greater* than is given by the preceding equation, and the earth will still resist the additional horizontal thrust; but that proportion should never be made *less* than the value given by the equation, or the side of the archway will be in danger of being forced inwards.

In a drainage tunnel or culvert, the entire ellipse may be used as the figure of the arch; but in a railway tunnel, where it is necessary to have a flat floor, the sides and roof of the tunnel comprise in height the upper two-thirds, or three-fourths, of the ellipse, which is closed below by a

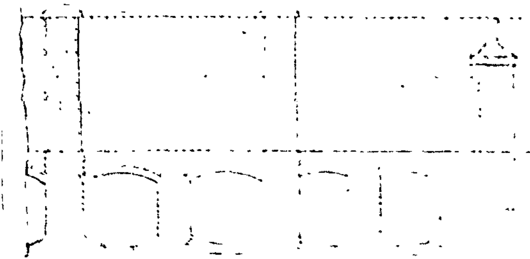
FLAT AND INVERTED ARCHES.

Inverted Arches

Flat and Relieving Arch over a door way



[illegible]



circular segmental inverted arch of slight curvature, its depression being one-eighth of its span, or thereabouts. By this mode of construction the vertical pressure of the sides of the tunnel is concentrated upon foundation courses, directly below them, from which they spring. The ratio which the entire width of the tunnel, measured *outside* the masonry or brickwork, bears to the joint width of that pair of foundations, must not exceed the limit of the ratio of the weight of a building to the weight of earth displaced by it. The inverted arch serves to prevent the foundations of the sides of the tunnel from being forced inwards by the horizontal pressure of the earth.

The exact form for the line of pressure in the sides and roof of a tunnel is the *geostatic arch*. This principle requires attention, when the roof of the tunnel is near the surface. Let X_0 be the depth of the crown of the tunnel, and X_1 that of its greatest horizontal diameter, beneath the surface. From those ordinates as data, design a *hydrostatic arch*; contract the horizontal ordinates of that arch in the ratio $c : 1$ (*see* equation 1); and the result will be the figure of the geostatic arch required.

The greatest intensity of pressure in a buried archway occurs usually in its sides, at the ends of the shorter diameter of the oval intrados; and that intensity is given approximately by the following equation. Let X_1 be the depth of the shorter diameter below the surface of ground, b' the half span of the archway, a' its rise, t the thickness of its side, w the weight of a cubic foot of the earth; then the greatest pressure in *lbs. on the square foot*, is

$$g = \frac{w \left\{ X_1 (b' + t) - 0\cdot 8\, a' b' \right\}}{t} \quad \text{..................} \quad (2).$$

and this should not exceed the resistance of the material to crushing, divided by a proper factor of safety.

It appears that in the brickwork of various existing tunnels, the factor of safety is as low as *four*. This is sufficient, because of the steadiness of the load; but in buried archways exposed to shocks, like those of culverts under high embankments, the factor of safety should be greater; say from *eight* to *ten*.

How small soever the load may be, there is a certain minimum thickness for an under-ground archway, for determining which the following empirical rule, (exactly similar to that for finding the depth of the keystone of an arch,) has been deduced from practical examples. The rise

and half-span being denoted as before by a' and b', compute approximately the longest radius of curvature of the intrados by the formula

$$r = \frac{a'^2}{b'} \text{ .... } (3).$$

then

$$\text{least thickness } t \text{ in feet} = \sqrt{0 \cdot 12\, r} \text{ .... } (4).$$

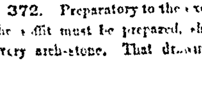
This is applicable where the ground is of the firmest and safest kind. In soft and *slippery materials*, the thickness ranges from *once and a half* to *double* that given by equation 4; that is to say,

$$\text{from } \sqrt{0 \cdot 27\, r} \text{ to } \sqrt{0 \cdot 48\, r} \text{ .... } (4a).$$

The thickness of an under-ground arch at the crown may be made less than at the sides in the ratio $b' : a'$; but the more common practice is to make it uniform.

371. Oblique Arches.—In the arches that have been hitherto described, the plan is rectangular, the faces of the abutments being perpendicular to the front of the arch, and each course of masonry is laid parallel to the abutments. In a *skew* or *oblique* arch, it is not possible to lay the courses parallel to the abutments, for, were this done, the thrust being at right angles to the direction of the courses, there would be a great portion of the arch on each side that would have nothing to keep it from falling. In order to obviate this, the courses must be laid at right angles to the faces of the arch, and at an angle with the abutment, and this it is which produces the peculiarity of the skew arch. When such arches are built of stone, much nicety is required in shaping the voussoirs, but with brick they may be built with nearly as much facility as ordinary arches.

The difficulties attending the construction of oblique arches, have been avoided by *indenting the face* of the abutments, and building the arch in cylindrical rings (*see* marginal cut), but this, though successfully executed in several bridges over Railways in Europe, is manifestly a make-shift; the extrados is irregular, and there can be no thorough bonding of the ribs composing the arch.

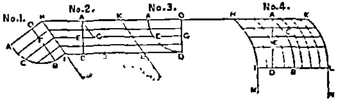


372. Preparatory to the execution of a skew arch, a large drawing of the soffit must be prepared, showing the exact figure and position of every arch-stone. That drawing represents the curved surface of the

soffit as if it were *spread out flat*, and is called the "*development*" of that curved surface. In general it is sufficient to draw one-half of the soffit, the other half being similar. The following are the processes by which that drawing is prepared:—

I. *To draw the development of the soffit, and of its vertical sections on the skew.*—In *Fig.* 1, No. 2 represents a plan of one-half of the arch,

Fig. 1.



HAK being the crown of the soffit, and IBL the face of the one of the abutments. The line ACB represents the position of a vertical section *on the skew*, and AED, perpendicular to HK, that of a vertical section *on the square*; BAD being the angle of obliquity.

Assume any convenient number of points in HI, through which draw a set of lines (such as ECEG) parallel to HK, and also a set of lines perpendicular to HI. Draw OB parallel to HI, cutting these lines; and on OB as half-span, construct the vertical section of the arch *on the skew*, represented by No. 1, in which ACB is the line on the soffit corresponding to ACB in No. 2.

Construct the vertical section *on the square*, (No. 3,) by drawing OD parallel to AD to represent the half-span on the square, and transferring the ordinates of No. 1 to the corresponding points in No. 3, for example, FC to GE.

Then construct the development No. 4 in the following manner:—Produce the centre line of the soffit, HAKAOHAK. From any convenient point A, (No. 4,) draw AED perpendicular to HK, in which take distances AE, AD, &c., &c., equal in length to the arcs AE, AD, &c., which are cut off on the curve AED, (No. 3,) by its several ordinates. Then will the straight line AED, (No 4,) be the development of the *section on the square*, AED, (Nos. 2 and 3) Through the points of division of AED, (No. 4,) draw lines parallel to HK, such as EC, IDBL, &c, on which lay off ordinates, such as EC, DB, &c., equal, respectively, to the corresponding ordinates, EC, DB, &c, in the plan, (No. 2,) and through the ends of those ordinates draw a curve ACB, (No. 4); this

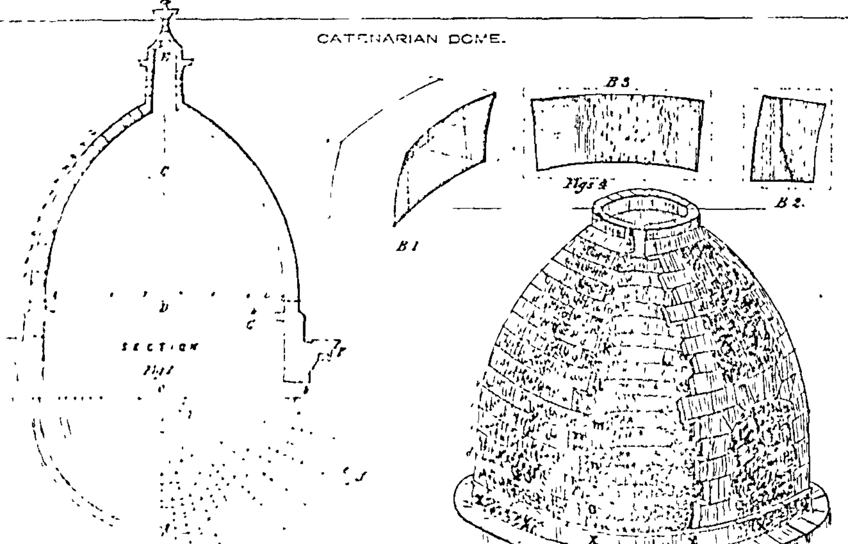
The line in which all the planes that pass through the vertical joints intersect, is called the *axis* of the dome. The circumference of the horizontal circle, which passes through the centre of the spheric surface, is called the *equatorial circumference*, and any portion of this curve is called an equatorial arc. The circumferences of all the courses of stones above the base or springing-line of the dome, which are parallel to the equatorial circle, are called *parallels of altitude.* The intersection of the axis and the spheric surface is called the *pole of the dome.* The arcs, between the pole and the base of the dome, of the circles formed on the curved surface by planes which pass along the axis, are called the *meridians,* and any portion of these meridians are called meridional arcs. The conical surfaces of the coursing joints terminate upon the hemispheric surface of the dome in parallels of altitude, and the surfaces of the vertical joints terminate in the meridional arcs.

Hence, in domes where the extrados and intrados are obtained by concentric hemispherical surfaces, two apparent sides of each stone, contained between two meridional arcs and the arcs of two parallel circles, are spheric rectangles, the two sides, forming their vertical joints, being two equal and similar frusta of circular sectors ; and the other two sides, forming the beds of the stones, are frusta of *conic* surfaces.

It is universally admitted, by those who have paid attention to the forms of domes, that the strictly semi-circular sectional shape is wanting in grace and that imposing effect of altitude and dignity so eminently conducive to grandeur of result, and more particularly for its strength. The upper part of a semi-circular dome presenting a surface for some extent comparatively flat, does not offer the advantages for equalising the pressure around its centre and some distance down towards its springing, as a dome worked from two centres. In illustration of this, we refer our readers to the *Plate,* No. XLVIII., in which it will be observed, that satisfactory effects may be produced by using the most simple means with the greatest facility, by adopting the parabolic or catenarian forms, such as were employed at St. Peter's, at Rome ; the Pantheon, Paris ; and St. Paul's Cathedral, London.

In producing the peculiar form of dome, as shown, *Fig.* 1, divide the internal base line AB into 7 equal parts, then erect the perpendicular line DCE at right angles to it, and from the centre D describe the semicircle ACB, as shown by the dotted line, which in contrast with the

CATENARIAN DOME.



line of the outer dome, as displayed at 1, 2, 3, 4, &c., proves the inferiority of the purely semi-circular form.

To find the centre for describing the outer curve of the dome, at the division 6 of the base line AB, make the line 6G at right angles to it, and equal to one-fourth of one of the divisions A1—1, 2, &c., when the point G gives the centre from whence the outer curve is drawn, and also is the centre from which all the joints must radiate that form the outer crust of the dome. F is the cornice at the springing of the dome, and below it is a portion of what is techincally called the drum or tambour of the structure. It is most desirable to give to the base of the dome a portion of the vertical above the cornice, to compensate for a part of the fore-shortening in perspective, caused by the projection of the cornice, and prevent that appearance of the curve having been described much below the uppermost line of the cornice.

Fig. 2 is the half plan of the dome, taken through the lantern, with its cornice and tambour, showing all the horizontal and vertical joints of the work. It is scarcely necessary to observe, as will be seen, that the whole of the vertical joints must tend accurately to the centre O.

Fig 3 exhibits the elevation of a dome in perspective, on which the two usual modes of construction are illustrated. The left side is formed in horizontal courses, and the right by means of stone ribs, filled in between with rubble-work or concrete, the latter mode, having been adopted in the building of the Pantheon, at Rome. XXXXXX is the equatorial line of the dome; the lines *dd*, *ee*, *ff*, and *gg*, &c., are the parallels of altitude.

Fig. 4, illustrates the form of the stones required in the construction of a dome of this description. B1 shows the shape of the stone in perspective, after having been hewn from the rough block. B3, is the plan of the stone at its lower bed, and B2 is its end elevation. It has been already observed, that the whole of such stones are spherical rectangles, the extrados, or upper surfaces, of which, are of course convex, and their intrados, or under surface concave. In the sectional cut through the dome, at *o*, *n*, *m*, *l*, *k*, and *h*, the ends of the stones are seen in perspective, and at D is shown a void or opening at the top, with the base for a lantern.

375. Constructively considered, it must be borne in mind that the stability of a dome depends upon the proper application and action of a

line of the outer dome, as displayed at 1, 2, 3, 4, &c., proves the inferiority of the purely semi-circular form.

To find the centre for describing the outer curve of the dome, at the division 6 of the base line AB, make the line 6G at right angles to it, and equal to one-fourth of one of the divisions A1—1, 2, &c., when the point G gives the centre from whence the outer curve is drawn, and also is the centre from which all the joints must radiate that form the outer crust of the dome. F is the cornice at the springing of the dome, and below it is a portion of what is techincally called the drum or tambour of the structure. It is most desirable to give to the base of the dome a portion of the vertical above the cornice, to compensate for a part of the fore-shortening in perspective, caused by the projection of the cornice, and prevent that appearance of the curve having been described much below the uppermost line of the cornice.

Fig. 2 is the half plan of the dome, taken through the lantern, with its cornice and tambour, showing all the horizontal and vertical joints of the work. It is scarcely necessary to observe, as will be seen, that the whole of the vertical joints must tend accurately to the centre O.

Fig. 3 exhibits the elevation of a dome in perspective, on which the two usual modes of construction are illustrated. The left side is formed in horizontal courses, and the right by means of stone ribs, filled in between with rubble-work or concrete, the latter mode, having been adopted in the building of the Pantheon, at Rome. XXXXXX is the equatorial line of the dome; the lines *dd*, *ee*, *ff*, and *gg*, &c., are the parallels of altitude.

Fig. 4, illustrates the form of the stones required in the construction of a dome of this description. B1 shows the shape of the stone in perspective, after having been hewn from the rough block. B3, is the plan of the stone at its lower bed, and B2 is its end elevation. It has been already observed, that the whole of such stones are spherical rectangles, the extrados, or upper surfaces, of which, are of course convex, and their intrados, or under surface concave. In the sectional cut through the dome, at *o*, *n*, *m*, *l*, *k*, and *h*, the ends of the stones are seen in perspective, and at D is shown a void or opening at the top, with the base for a lantern.

375. Constructively considered, it must be borne in mind that the stability of a dome depends upon the proper application and action of a

very different principal, from that which operates in the case of the ordinary arch; and, as a general rule, being correctly built with reference to such different and peculiar principle, its relative security and power is greater and more extended. The dome also differs in another important point, namely, it may be left unperfected, or open at the apex or top, as represented in the *Plate* just referred to. This is owing to the several joints of the masonry being formed to tend equally in every part to the centre of the hemisphere as a common centre. 'In an arch of equilibrium, therefore, such as the dome essentially is, the open apex or unclosed top, may exist without prejudice to its power of sustaining any minor or superincumbent structure, (such as the usual feature of a lantern before-mentioned,) the weight of which shall not exceed that of the crowning circular segment of the dome which is omitted. A load greater than this would so act as to dislodge the upper portion of the dome, by causing an upward spring or tendency in some of the courses near the opening.

376. If a dome rises nearly vertical with its form spherical, and of equal thickness, it should be confined by a chain or hoop, as soon as the rise reaches to about $\frac{1}{4}$ths of the whole diameter, in order that the lower parts may not be forced out: but if the masonry be diminished in thickness as it rises, this precaution will not be necessary.

Where the weight of a dome is equally distributed over the area, then the curve of equilibrium is a cubic parabola, and if $\frac{1}{8}$th of the weight supported be multiplied by the diameter, and the result divided by the rise, the quotient is the horizontal thrust ending to separate and over-set the supporting wall.

When the weight increases from the centre to the circumference in proportion to the distance from the centre, then the curve is a biquadrate parabola, $\frac{1}{8}$th of the weight should be taken instead of $\frac{1}{8}$th.

The horizontal thrust of the dome will be wholly counteracted by a resistance to tension in the circle, equivalent everywhere to $\frac{1}{6}$th the horizontal thrust: and when this strain is amply provided for, either by the bond and substance of the walls at the springing, or by chains of iron, the dome will be secure at whatever height from the ground it may spring, if the vertical walls or pillars be sufficiently strong to resist the weight upon them.

377. Vaulting is an application of the arch principle to a lengthen-

ed area; a *vault* being an arched covering of greater or less continuance, spanning a more or less extended space.

A cylindrical vault is simply a semi-circular arch, the ends of which are closed by upright walls, as shown in *Fig.* 1. When a vault springs from all the sides of its plan, as in *Fig.* 2, it is said to be *coved*. When

Fig. 1.

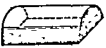


Fig. 2.

Fig. 3.

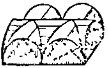


Fig. 4.

two cylindrical vaults intersect each other, as in *Fig.* 3, the intersections of the vaulting surfaces are called *groins*, and the vault is said to be *groined*.

In the Roman style of architecture, and in all common vaulting, the vaulting surfaces of the several compartments are portions of a continuous cylindrical surface, and the profile of a groin is simply an oblique section of a semi-cylinder.

Gothic ribbed vaulting is, however, constructed on a totally different principle. It consists of a frame-work of light stone ribs supporting thin panels, whence this mode of construction has obtained the name of *rib and panel* vaulting. The curvature of the diagonal ribs or cross springers, and of the intermediate ribs, is not governed in any way by the form of the transverse section of the vault, and in this consists the peculiarity of ribbed vaulting. This will be understood by a comparison of *Figs.* 3 and 4.

In Roman vaulting when the diameter of the intersecting circular cylinder are inequal, the vault is called by workmen a *Welsh groin*.

378. *Principles of Brick-vaulting.*—It is beyond the province of this work to describe in detail the mode of construction of the numerous and varied kinds of ribbed vaulting adopted in different countries and ages: and which adorn the Cathedrals of England and Europe.

The principal mediæval forms were the "Plain ribbed," the "Lierne" and the "Fan" vaults: differing much from one another in architectural design and mechanical construction. Ribbed vaulting subsequently fell into disuse and the principle of solid vaulting with elliptic groins was renewed.

For the vaults none but the best and hardest bricks should be used, the joints should be as fine as possible, and cemented with hydraulic mortar very thoroughly ground.

In vaults not intended to bear any great extra weight, the mortar should be allowed to set thoroughly before the removal of the centering, especially as from their thinness and exposure to the atmosphere, it will be difficult to prevent the joints from setting partially before the vault is completed, and this partial setting would probably be the cause of cracks in the vault from unequal resistance to the settlement of the brick-work.

381. *Centering.*—A substantial centering to support the whole roof, must be prepared; but if it is not probable that the centering will soon be required for other buildings, it will often be more economical to adopt the Indian mode, consisting of numerous pillars of bricks cemented with mud, connected at top with strong rough timber, over which is laid brick-work, like that of the pillars, to obtain the curve intended for the vault, which is finished and made quite smooth, by a plaster of soorkee mixed with cow-dung. The curve should be gauged with wooden frames like an inverted arch, to ensure its accuracy, and it will be well to mark on the sides of this gauge, the joints of the intended arch, so as to render it easy for the bricklayers, by having two or three of them on the roof, to lay each course of bricks at right angles with the curve of the arch, by stretching a string through holes made in the gauge.

Small holes should be left at intervals in the centering above described, to carry off the superfluous water (which should be plentifully used) in dry weather, and the rain water, in wet.

This kind of centering costs little more than the labor, since all the bricks may be afterwards employed in making the floors, or drains of the building. If, however, a movable centering is perferred, it should be made with wooden ribs whose upper surface is planed to the curve required, the ribs being supported by struts either from brick pillars, or wooden posts carried to the height of the springing, and supporting a tie-beam or sill with the intervention of wooden wedges for lowering it.

Across the ribs in the direction of the purlins of a roof is placed the lagging, consisting of strong bamboos, fir lathes, about 2 inches square, or other similar material; by making all the parts of a center-

ing of such strength as to bear the strain upon it without deflection, and by cutting as few mortices as possible, the timber will be almost uninjured, and the cost will be limited to that of the labor employed in its erection; wide planking should not be used in India as lagging, as it is very apt to warp.

382. When the centerings are fixed and materials all at hand, a sufficient number of bricklayers should be ready to carry on the work by even courses all round, so that no part of the arch should be built up higher than another, by which means an equal pressure is maintained.

The joints should be as fine as possible, and each brick should be bedded into the cement and worked firmly into its place, where it should be fixed with one or two blows of the hand or a small wooden mallet.

The courses should break joint with each other, making the joints of every upper course fall as nearly as possible upon the middle of the bricks in the course immediately beneath it. This principle should be strictly adhered to in every kind of building, for in all the various modes of laying stones or bricks, the uniform object is to obtain the greatest lap of one over the other.

By moulding a proportion of the arch bricks half breadth, and placing a half brick occasionally, the joints may be made to fall exactly in the middle of those in the course below. The joints between the courses should be as fine as possible, and the last courses forming the keying of the arch should be put in very tight.

This should be done, not by hammering the keying bricks, but by taking care to leave a space at the crown somewhat less than the thickness of the last brick or two bricks to be placed, and by then inserting two planks with wedges between them, by driving which the aperture may be increased so as to admit the keying bricks without the application of any great force. Another advantage will be that the joints on each side of the crown will be thereby compressed to the same extent as, or even to a greater, than those lower down the arch, which have been compressed by the hammering of each layer of brick by wooden hand-mauls, and by the weight of the brickwork subsequently laid upon them.

The centering or support to the roof may remain up till the brickwork is slightly dried, and is then to be carefully removed by lowering it gradually. By allowing arch-roofed buildings to remain one rainy season without plaster or terrace on the roof, the outer surface becomes less

These roofs should be plastered inside, and covered with a well beaten terrace outside; the beating requires care, but can be effected without the slightest injury, if the voussoirs are sound; the roof is then weather-tight, and indestructible; and in many countries less costly too, than a well-timbered roof of equal span, and not requiring thicker walls than are usually built in India for flat and pitched roofs: of course these roofs must not be carried to an extent that would crush the materials.

The only chance of subsequent failure arises from the presence of crystallizing salts in the pottery: this would cause gradual decay of the voussoirs, which would communicate itself to the mortar: roofs of this kind exist over some gunsheds in the Fort at Agra, and although in many parts of the Fort corrosion by the efflorescence of salts is very destructive, these roofs appear to have escaped its influence.

385. Sindh Roof.—The construction of the peculiar hexagonal tiles used in this kind of roof has been already described in para. 60. This roof is very light, and the use of a centering can generally be dispensed with.

It is also cheap, costing Rs. 8 per 100 square feet, measured on the voussoir portion only, which is about equal to the area of the floor of each room. This rate covers the outside plaster (of mud.) Where lime plaster is used, of course the vault costs proportionally more. The Sindh bricklayers are very dexterous in using these voussoirs, and the roof of one of the rooms (18 × 22 feet) of a District Bungalow, was vaulted in two days by two bricklayers.

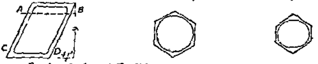
The Syrian roof of course possesses the same advantage of quick construction, where seasoned timber is not procurable, but it is not quite so quick as the voussoir plan, as the construction and removal of the centering occupy time.

The mode of constructing a vault with Sindh tiles is illustrated in the accompanying figure, which is a developed plan of a vault during construction, as seen when looking down upon it from above.

The side and end walls having been carried up to the requisite full height, the first voussoir (1 in figure) is let into the end wall (at the crown of the curve); other voussoirs (2, 3, to 7 in figure) at proper intervals are then similarly let into the wall, till the haunches are reached. About one-half of each voussoir ought to project beyond the face of the wall, (inwards towards the room being roofed in), and the interval between each should be

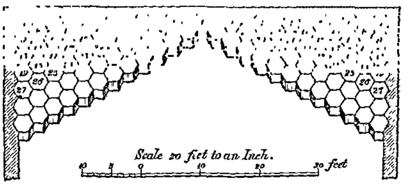
sufficiently large for the reception of half a voussoir and its cement. The vaulting is then commenced at the angles, which are gradually filled in, each course of voussoirs being commenced at the end wall, and carried obliquely down to the haunch in the following manner :—The sides of voussoirs 6 and 7, and the face of the bit of wall between them being covered with cement, No. 8 voussoir is thrust in (care being taken in *doing so to keep the top parallel to the direction of the vault)* with two or three blows from the hand. It penetrates like a wedge, making the joints quite smooth. After this, the joints should be closed above and below, to make them air-tight, till the clay has stiffened a little. No. 9

Section of Hollow Voussoir. *Section A, B.* *Section C, D.*



Developed plan of Vault in course of construction.

END WALL.



is then thrust into its place in the same way as No. 8, forcing the latter, if it is possible, still tighter into its place. This completed, No. 10 in the next course is placed; and so on throughout the whole length of the vault. The numbers on the figure denote the order in which the voussoirs are inserted.

It will be observed, that by laying the voussoir course along the haunches of the vault in advance of the courses higher up, any settlement at the crown is prevented. Two sides of each voussoir being perpendicular to the direction of the course, they are directly opposed to any settlement. The vault is kept in the proper curve by a circular piece of plank, standing on the projecting bricks of the cornice; and so little settlement takes place, that this can be made to slide back under the completed portion of the vault.

The voussoirs run about 450 to 100 square feet, and a workman tolerbly expert can vault 40 square feet in a day. From the small number of voussoirs required, and the small quantity of cement used, he requires very little assistance.

In all the vaults constructed on this plan, mud and bhoosa has been the cement used, and it has been found quite sufficient. Being thrown against the voussoirs, and spread with the hand, it will be found more expeditious than chunam, and of course more economical.

Before commencing to construct the vault as just described, it is well to carry their haunches up as far as ever they will stand securely without the assistance of the thrust from the vault, for the more the centre of gravity of the wall and haunch is brought inwards in this manner, the greater is the stability of the structure when completed. It was found from experiment that the haunches of a semi-circular vault of 15 feet span could be carried up to a height of 5 feet. To prevent, however, accidents from a number of workpeople congregating on them before the vaulting was commenced, the haunches were carried up to a height of 4 feet in the first instance, completing them to the requisite height while the vaulting was being executed.

CHAPTER XIX.

FOUNDATIONS.

386. The term *Foundation* is used indifferently either for the lower courses of a structure of masonry, or for the artificial arrangement, of whatever character it may be, on which these courses rest, and which may be more precisely termed the *bed of the foundation.* The latter alone will be treated of here.

The strength and durability of structures of masonry depend essentially upon the bed of the foundation. In arranging this, regard must be had not only to the permanent efforts which the bed may have to support, but to those of an accidental character. It should, in all cases, be placed so far below the surface of the soil on which it rests, that it will not be liable to be uncovered, or exposed; and its surface should not only be normal to the resultant of the efforts which it sustains, but this resultant should intersect the base of the bed so far within it, that the portion of the soil between this point of intersection and the outward edge of the base, shall be broad enough to prevent its yielding from the pressure thrown on it.

387. The object to be attained in the construction of any foundation is, to form such a solid base for the superstructure that no movement shall take place after its erection. We must bear in mind that all structures built of coursed-masonry (whether brick or stone) will settle to a certain extent, and that, with a few exceptions, all soils will become compressed, more or less, under the weight of a building, however trifling its character. Our aim, therefore, will be not so much to attempt to *prevent* settlement, as to ensure that it shall be *uniform*, so that the superstructure may remain without crack or flaw, however irregularly disposed over the area of its site, and it cannot be too strongly impressed on the mind of the reader, that it is not an *unyielding*, but a *uniformly yielding* foundation that is required, and that it is not the *amount*, so much as the *inequality* of settlement that does the mischief.

The second great principle in preparing foundations is, to prevent the lateral escape of the supporting material.

The principles, therefore, to be kept in view in the treatment of all

cases where the natural soil is at all of a doubtful character, may be thus briefly stated:—

1st. To distribute the weight of the structure over a large area of bearing surface.

2nd. To prevent the lateral escape of the supporting material.

388. **Nature of Subsoils.**—The first preparatory step to be taken, in determining the kind of bed required, is to ascertain the nature of the subsoil on which the structure is to be raised. This may be done, in ordinary cases, by sinking a pit; but where the subsoil is composed of various strata, and the structure demands extraordinary precaution, borings must be made with the tools usually employed for this purpose.

389. With respect to foundations, soils are usually divided into three classes:—

The 1st class consists of soils which are incompressible, or at least, so slightly compressible, as not to effect the stability of the heaviest masses laid upon them, and which, at the same time, do not yield in a lateral direction. Solid rock, some tufas, compact stony soils, hard clay which yields only to the pick, or to blasting, belong to this class.

The 2nd class consists of soils which are incompressible, but require to be confined laterally, to prevent them from spreading out. Pure gravel and sand belong to this class.

The 3rd class consists of all the varieties of compressible soils; under which head may be arranged ordinary clay, the common earths, and marshy soils. Some of this class are found in a more or less compact state, and are compressible only to a certain extent, as most of the varities of clay and common earth; others are found in an almost fluid state, and yield with facility in every direction.

390. *Rock.*—To prepare the bed for a foundation on *rock*, the thickness of the stratum of rock should first be ascertained, if there are any doubts respecting it: and if there is any reason to suppose that the stratum has not sufficient strength to bear the weight of the structure, it should be tested by a trial weight, at least twice as great as the one it will have to bear permanently. The rock is next properly prepared to receive the foundation courses, by levelling its surface, which is effected by breaking down all projecting points, and filling up cavities with concrete (which once set is nearly incompressible with anything short of a crushing force, whereas in masonry, the compression of the mortar joints is certain

to cause some irregular settlement), and by carefully removing any portions of the upper stratum which present indications of having been injured by the weather. The surface, prepared in this manner, should, moreover, be perpendicular to the direction of the pressure; if this is vertical, the surface should be horizontal; and so for any other direction of the pressure. If, owing to a great declivity of the surface, the whole cannot be brought to the same level, the rock must be broken into steps, in order that the bottom courses of the foundation throughout, may rest on a surface perpendicular to the direction of the pressure. If fissures or cavities are met with, of so great an extent as to render the filling them with masonry too expensive, an arch must then be formed, resting on the two sides of the fissure, to support that part of the structure above it. The slaty rocks require most care in preparing them to receive a foundation, as their top stratum will generally be found injured to a greater or less depth by the action of frost.

391. *Hard Earths.*—In stony earths and hard clay, the bed is prepared by digging a trench wide enough to receive the foundation, and deep enough to reach the compact soil which has not been injured by the action of frost or heavy rain: a trench from 4 to 6 feet, will generally be deep enough for this purpose.

In dealing with *clay*, the less it can be exposed to the air and the sooner it can be covered up, the better for the work. If the foundations are not so deep as to be beyond the influence of alternate droughts and moisture, heat and cold, the bottom of the foundation pit must be covered with a concrete stratum (as described in next para.), otherwise the building may become rent or seriously injured by the contraction or expansion of the ground on which it rests.

In compact gravel, and sand, where there is no liability to lateral yielding, either from the action of rain or any other cause, the bed may be prepared as in the case of stony earths. If there is danger from lateral yielding, the part on which the foundation is to rest must be secured by confining it laterally by means of sheeting piles, or in any other way that will offer sufficient security.

392. *Compressible Earth.*—The beds of foundations in compressible soils require peculiar care, particularly when the soil is not homogeneous, presenting more resistance to pressure in one point than in another; for, in that case, it will be very difficult to guard against unequal settling.

In ordinary clay, or earth, a trench is dug of the proper width, and the bottom of the trench is levelled off to receive a foundation of béton.

The preparation of an area of béton for the bed of a foundation, will depend on the circumstances of the case. In ordinary cases, the béton is spread in the trench, and carefully rammed in layers of 6 or 9 inches, until the mortar collects in a semi-fluid state on the top of the layer. If the base of the bed is to be broader than the top, its sides must be confined by boards suitably arranged for this purpose. Whenever a layer is left incomplete at one end, and another is laid upon it, an off-set should be left at the unfinished extremity, for the purpose of connecting the two layers more firmly when the work on the unfinished part is resumed.

393. *Wet Soils.*—When the soil under the bed is liable to injury from springs, they must be cut off, and an area of béton should compose the bed, which should be confined on all sides between walls of stone or béton sunk below the bottom of the bed.

When springs rise through the soil over which the béton is to be spread, the water from them must either be conveyed off by artifical channels, which will prevent it rising through the mass of béton, and washing out the lime; or else strong cloth, prepared so as to be impermeable to water, may be laid over the surface of the soil to receive the bed of béton. When artificial channels are used, they may be completely choked subsequently by injecting into them a semi-fluid hydraulic cement, and the action of the springs be thus completely destroyed.

If, in opening a trench in sand, water is found at a slight depth, and in such quantity as to impede the labors of the workmen, and the trench cannot be kept dry by the use of pumps, or scoops, a row of sheeting piles may be driven on each side of the space occupied by it, somewhat below the bottom of the bed, the sand on the outside of the sheeting piles being thrown out, and its place filled with a puddling of clay, to form a water-tight enclosure round the trench. The excavation for the bed is then commenced; but if it be found that the water still makes rapidly at the bottom, only a small portion of the trench must be opened, and after the lower courses are laid in this portion, the excavation will be gradually effected, as fast as the workmen can execute the work without difficulty from the water.

394. *Marshy Soils.*—In marshy soils, the principal difficulty consists in forming a bed sufficiently firm to give stability to the structure,

owing to the yielding nature of the soil in all directions. Although the difficulties of building upon treacherous soil are great, they are not unsurmountable; and where capital and talent are available, satisfactory results are almost invariably obtained.

The following five methods are simple expedients for providing a firm foundation bed in marshy soil, any one of which may be adopted with success according to circumstances. The first, and beyond question the best, is to drive piles down to the hard substratum underlying the alluvial deposit, (as described in more detail in the next paragraph,) to plank over their heads, and to build on the platform so made; the same object may be attained, usually at greater cost, by excavating down to the hard bottom, and filling up the trench with concrete.

The second system was adopted by General Gilmore in constructing the "Swamp Angel" battery, used in the siege of Charleston. It consists in driving sheeting piles down to the hard bottom, but not necessarily into it, so as to enclose a circular or rectangular column of alluvium. On top of this, hurdles or fascines are laid, and over these a timber platform which will carry guns, or, if need be, a fort. The theory of the arrangement is, that before the superstructure can sink into the mass of loose earth, a portion of the latter must be displaced laterally, in a way that may be best expressed by the theory of the fluidity of solids, as defined by M. Tresca and others. The sheeting piles prevent this displacement, and the load is supported much as though it reposed on the ram of a gigantic hydraulic press, of which the piles formed the cylinder, while the semi-solid mud took the place of the water. Such an expedient should be resorted to with much caution, as the stability of the structure depends altogether on the power which the sheeting piles possess of resisting pressure from within.

The third is also a plan which may often be pursued with success. Short piles from 6 to 12 feet long, and from 6 to 9 inches in diameter, are driven into the soil as close together as they can be crowded, over an area considerably greater than that which the structure is to occupy. The heads of the piles are accurately brought to a level to receive a grillage and platform; or else a layer of clay, from 4 to 6 feet thick, is laid over the area thus prepared with piles, and is either solidly rammed in layers of a foot thick, or submitted to a very heavy pressure for some time before commencing the foundations. The object of preparing the bed in this manner, is to give the upper stratum of the soil all the firmness

possible, subjecting it to a strong compression from the piles; and when this has been effected, to procure a firm bed for the lowest course of the foundation by the grillage, or clay bed; by these means the whole pressure will be uniformly distributed throughout the entire area. This case is also one in which a bed of béton would replace, with great advantage, either the one of clay, or the grillage.

The practice, however, of driving small piles into the ground to consolidate it, is considered by many Engineers as having the effect only of pounding up the soil, and bringing it into a state which can best be described by comparing it to batter pudding.

Instead of *driving* piles in these cases, if the ground, though soft, is of tolerable consistency, a better plan is the fourth method now recommended, viz., to *bore* holes with a large auger to a considerable depth, and to fill them with sand, which from its property of acting almost as a fluid, is a most valuable material for distributing pressure over a large area of surface. In the case of a timber pile, the pressure is transmitted only in the direction of its length; but a *sand pile* transmits the pressure laid on it, not only to the bottom, but to the sides of the excavation, and does not injure the ground by vibration. It must be borne in mind that sand piling is inapplicable in very loose wet soils, as the sand would work into the surrounding ground.

The fifth system may be described as consisting in constructing an extended platform of timber, which will diffuse the insistent weight over so large an area, that, what we may term, the co-efficient of resistance proper to the soil of the marsh may not be exceeded, and the work will therefore, so to speak, float as though on a raft, or be carried like a man in snow shoes. It is evident that this system can only be properly applied on a comparatively small scale, and in any case, much care should be taken not only to make the platform sufficiently large, but to construct it in such a way, that it may not yield where the load is greatest, while portions less severely taxed remain at the surface.

395. Piles.—To prepare the bed to receive the foundations according to the first of the five methods above-mentioned, strong piles are driven at equal distance apart, over the entire area on which the structure is to rest. These piles are driven, until they meet with a firm stratum below the compressible one, which offers sufficient resistance to prevent them from penetrating farther.

Piles are generally from 9 to 18 inches in diameter, with a length not above 20 times the diameter, in order that they may not bend under the stroke of the ram. They are prepared for driving, by stripping them of their bark, and paring down the knots, so that the friction, in driving may be reduced as much as possible. The head of the pile is usually encircled by a strong hoop of wrought-iron, to prevent the pile from being split by the action of the ram. The foot of the pile may receive a *shoe* formed of ordinary boiler iron, well fitted and spiked on; or a cast-iron shoe of a suitable form for penetrating the soil may be cast around a wrought-iron bolt, by means of which it is fastened to the pile.

396. *Pile Engine.*—A machine, termed a *Pile Engine,* is used for driving piles. It consists essentially of two uprights firmly connected at top by a cross piece, and of a *ram* or *monkey* of cast-iron, for driving the pile by a force of percussion. Two kinds of engines are in use; the one termed a *Crab engine,* from the machinery used to hoist the ram to the height from which it is to fall on the pile; the other the *Ringing engine,* from the monkey being raised by the sudden pull of several men upon a rope, by which the ram is drawn up a few feet to descend on the pile. The latter is generally used in India.

397. In calculating the effects of a ram in driving a pile, an approximate value may be obtained by assuming that the impact or force of the blow (in foot lbs.) $= w\sqrt{2gh}$, where

w = weight of ram in lbs.,
g = 32·2 feet,
h = fall of ram in feet,

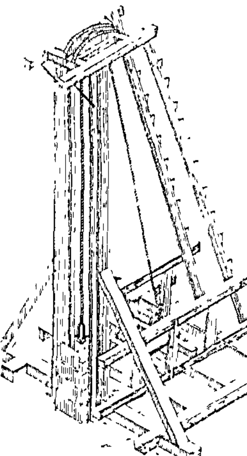
and that in *ordinary* cases if a pile will resist an *impact* of a ton, it will bear without yielding a *pressure* of $1\frac{1}{2}$ tons. In practice 30 feet may be considered the greatest fall which can be used without splitting the timber, and a ram exceeding two tons in weight would be very troublesome to move from place to place.

The French civil engineers have adopted a rule to stop the driving, when the pile has arrived at its *absolute stoppage,* this being measured by the farther penetration into the subsoil of about $\frac{2}{10}$ths of an inch, caused by a volley of thirty blows from a ram of 800 lbs., falling from a height of 5 feet at each blow. Piles should, however, when practicable, be driven to an unyielding subsoil.

When a pile from breaking, or any other cause, has to be drawn out, it

PILE DRIVERS AND PILES.

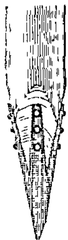
Crab Engine.



The Crab

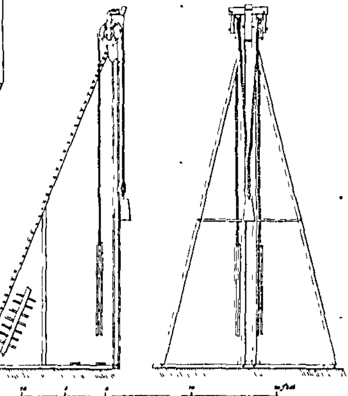
Pile with patent shoe

Pile with ordinary shoe



Scale [illegible] of full size

Ringing Engine



is done by using a long beam as a lever for the purpose; the pile being attached to the lever by a chain, or rope suitably adjusted.

But in many cases, (as where sheet piling has been driven round the foundations of any work,) there will be the risk of the ground settling down to fill up the vacancy caused by drawing the piles: and in all such cases, the piles should not be drawn, but cut off at the level of the ground, or such level as may suit the requirements of the work.

398. The number of piles required, will be regulated by the weight of the structure. An allowance of 1000 lbs. on each square inch of area of head will ensure safety. The least distance apart, at which the piles can be driven with ease, is about 2½ feet between their centres. If they are more crowded than this, they may force each other up, as they are successively driven.

From experiments carefully made in France, it appears that piles which resist only in virtue of the friction arising from the compression of the soil, cannot be subjected with safety to a load greater than one-fifth of that which piles of the same dimensions will safely support when driven into a firm soil.

After the piles are driven, they are sawn off to a level, to receive a grillage or platform on which the lowest courses of masonry are laid.

399. *Sheet piles* are flat piles, which being driven successively edge to edge, form a vertical or nearly vertical sheet for the purpose of preventing the materials of a foundation from spreading, &c.

They may be any breadth that can readily be procured, and from 2½ to 10 inches thick: and are sharpened at the lower end to an edge, which in stony ground may be shod with sheet-iron. Sheeting piles should be carefully fitted to each other before driving. In some cases it is worth while to tongue and groove the edges: but this is seldom done; and if the piles are perfectly parallel and truly driven, the swelling of the wood when exposed to moisture will generally secure a tight joint.

400. The objections to the employment of wooden piles in India are the numerous destructive agencies at work, and that, owing to the peculiar character of the water-courses, they would, when employed for bridges, be alternately wet and dry, and would soon rot.

These objections do not apply to *Iron-piles*, which are now very much employed both in England and India, and which possess great advantages, especially when used in the deep sandy beds of Indian rivers.

401. *Cast-iron piles* are of two kinds, bearing piles and sheeting piles.

The bearing piles may be either solid of section ✢, or hollow, (square or round.) Cast-iron piling will not last for any considerable length of time in *salt* water, as it becomes gradually softened, so that it can be cut with a knife. In driving iron piles, it is especially necessary to confine the fall within narrower limits, as a fall exceeding 4 or 5 feet, would be almost sure to fracture the metal. In all cases it is essential to interpose a piece of wood (called a *punch* or *dolly*) between the ram and the pile head to deaden the blow, and distribute the force equally over the pile head.

402. *Prestage's Expanding Piles.*—On the Eastern Bengal Railway, the worn out rails were utilized by Mr. Prestage for iron piling. The smallest form of pile was made of a pair of rails (weighing 21 lbs. to the foot), securely hooped together by wrought-iron collars (*a*) at intervals: the separate lengths of rail breaking joint and being fished in the ordinary manner. A wedge (*c*) at the foot of the pile is securely held in that position by a wrought-iron stop bar, which passing down from top to bottom between the rails, is bolted to the rails at the top by a jamb bolt. To the wedge are secured two links *d*, *d*; the other end of each of which is attached to an iron wing *f*. *Figs.* 1 and 3, shows the pile ready for driving.

The pile is driven in the ordinary way by a monkey travelling in guide frames. When the pile is down nearly to the required depth, the stop bar is removed, and on the monkey falling again on the pile, which consists now only of the two rails, these slide over the wedge, causing their feet to spread slightly apart: at the same time the links attached to the wedge being driven up towards a horizontal position, make the wings slightly expand: and as the driving continues, the full expansion of the rail-feet and wings is attained as shown in *Fig.* 2.

Fig. 1.

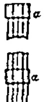


Fig. 2.

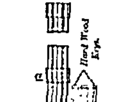


Fig. 3.

Modifications of this pile with the wings rivetted to the rails, and not hinged, were used: and larger piles on the same principle composed of a cluster of 8 rails were adopted, where a greater length of piling was required; as of course beyond a certain length the 2 rail piles would be liable to bend.

403. *Iron Screw Piles*, the invention of Mr. Alexander Mitchell, are piles which are screwed into the stratum in which they are to stand. The pile may be either of timber or iron, and that it may admit being easily turned about its axis, should be cylindrical, or at all events octagonal. The screw blade, which is fixed on at the foot of the pile, is usually of cast-iron, and seldom makes more than a single turn. Its diameter is from twice to eight times that of the shaft of the pile, and its pitch from one-half to one-fourth of its diameter. The best mode of driving screw piles is to apply the power of men or of animals, walking on a temporary platform, directly to levers radiating from the heads of the piles.

As an example may be cited, the wrought-iron piles used in the piers of railway bridges on the Bombay and Baroda Railway. Each of these was screwed into the ground by means of four levers, each 40 feet long, and each having eight bullocks yoked to it. According to this example, the greatest working load upon each screw of 4 feet 6 inches in diameter, *exclusive* of the earth and water above it, is nearly as follows:—

Pier 25 tons + superstructure 12 + train 30 = 67 tons = 150,080 lbs., being at the rate of nearly 100 lbs. per square inch of the horizontal projection of the screw blade.

As these piles are screwed from 20 to 45 feet into the earth, the weight of earth above each screw-blade may be taken as ranging from 14 lbs. to 30 lbs. per square inch; so that the load on each screw blade, exclusive of the weight of earth above it, ranges from 8 to 7 times that weight, and including the weight of earth, from 4 to 8 times.

The chief uses of screw piles are to form the vertical supports of platforms of open-work piers, whether of timber or iron, and of such structures as harbour-jetties and light-houses, and to fasten down permanent mooring-chains in harbours.

404. Tubular Foundations.—The description of these hollow wrought-iron screw piles leads us naturally from the consideration of Piles, to that of tubular foundations, which may be of cast-iron as used in Europe, or of masonry, as in the common *well* foundations of India.

405. Iron Tubular Foundations consist of large hollow vertical cast-iron cylinders, filled with rubble masonry or concrete.

The general construction of such cylinders and the mode of sinking them are shown in *Plate* LI. Amongst the auxiliary structures and machinery not shown in the figure are, a temporary timber stage from

which the pieces of the cylinder can be lowered, and on which the excavated material can be carried away; and a steam engine to work a pump for compressing air.

The cylinder consists of lengths of about 9 feet, united by internal flanges and bolts. The joints are cemented and made air-tight with a well-known composition, consisting of

Iron turnings, ...	1,000 parts by weight.
Sal-ammoniac, ...	10 " "
Flour of sulphur, ...	2 " "
Water enough to dissolve the sal-ammoniac.	

In some examples each joint is made tight by means of a ring-shaped cord of vulcanized indian rubber, lodged in a pair of grooves on the faces of the flanges.

The lowest length, A, of the cylinder, has its lower edge sharpened, that it may sink the more readily into the ground. The intermediate lengths, B, B, and the uppermost length, C, have flanges at both edges, upper and lower. *The portion D, at the top, forms the "bell."* The lower edge of the bell has an internal flange by which it is bolted to the cylinder below; its upper end is closed, and may be either dome-shaped, or flat, and strengthened against the pressure of the air within by transverse ribs, as in the figure. In the example shown, the bell is made of wrought-iron boiler plates.

E is a siphon, 2 or 3 inches in diameter, through which the water is discharged by the pressure of the compressed air.

F and G are two cast-iron boxes, called "air-locks," by means of which men and materials pass in and out. Each of them has at the top a trap door, or lid opening downwards from the external air, and at one side, a door opening toward the interior of the bell, and is provided with stop cocks communicating with the external air, and with the interior of the bell respectively, which can be opened and closed by persons either within the bell, within the box, or outside of both. These may be called the escape cock and the supply cock.

The bell is provided with a supply of pipe and valve for introducing compressed air, a safety valve, a pressure gauge, and a large escape valve for discharging the compressed air suddenly when required.

At the lower flange of the division C is a timber platform, on which stands a windlass.

SCREW PILES AND IRON TUBULAR FOUNDATION

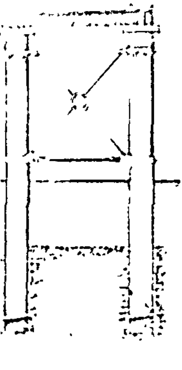
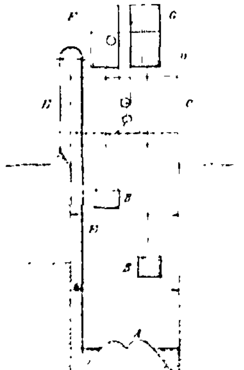
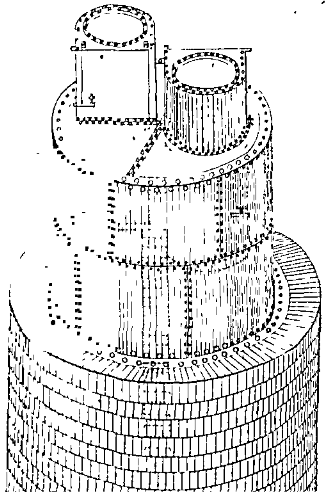


Diagram showing the working of the Pneumatic Apparatus



Pneumatic apparatus as used on Well or Tubular Foundations.



The apparatus is represented as working in a stratum of earth or mud, covered with water.

When the sinking of the cylinder has been completed, it is filled with masonry, or with hydraulic concrete. About one-half of the building is performed in the compressed air; the remainder, with the cylinder open at the top, the bell being removed.

Care should be taken to pack the concrete or masonry well below, and to bed it firmly above each of the pairs of internal flanges.

In very soft materials it is sometimes necessary to drive a set of bearing piles in the interior of each cylinder, in order to support the concrete and masonry.

The earliest mode of sinking iron tubular foundations, was that invented by Dr. Potts, in which the air is *exhausted* by a pump from the interior of the tube, which is forced down by the pressure of the atmosphere on its closed top. This method is well suited for sinking tubes in soft materials that are free from obstacles, which the edge of the tube cannot cut through or force aside—such as large stones, roots, pieces of timber, &c.*

406. WELL FOUNDATIONS.—*The general substitute for Iron Tubular* foundations in India are *Well* or *Block Foundations*, which have been in use for very many years, and which are peculiarly adapted to the deep sandy beds of Indian rivers, and are extensively used both for bridges and buildings. A foundation may consist of a number of wells, sunk close together, and connected together afterwards; or of a block or blocks of masonry made to the required shape, and having holes left in it of the same size as the wells; the latter however requires experienced workmen, and circular wells are therefore generally used. In both cases the method employed is the same. A wooden curb *(neemchuk)* of hard wood, and of a thickness varying from 6 to 18 inches, is made of the size of the well or block, and fixed in position on the river bed. On this about 4 feet in height of masonry is built; and when dry, the sand inside is scooped out, so that the curb and masonry descend. Another 4 feet is then built, and again the same process is resorted to, and the curb again made to descend until any required depth is attained.

* The method of sinking cylinders for foundations by the aid of compressed air, was first employed at the bridge over the Medway at Rochester, executed from the designs of Sir William Cubit.

It was at first intended that the tubes should be sunk by the exhaustive process; but the remains of an old timber bridge, imbedded in the mud at the bottom of the river, rendered that impracticable; and the compressive process was then invented by the contractor, Mr. Hughes, M.I.C.E.

Great care has to be taken that the sand is scooped out gradually and evenly all round, so that the masonry may not crack in its descent. The masonry must be thoroughly bonded, and of the best materials. In important works hoop-iron and vertical iron rods in the masonry (*vide* para. 412) are used to give additional strength.

407. The wells or blocks are either driven down to the solid soil, clay, or kunkur, or rock; or they may be suspended as it were in the sand by mere friction, the force of which is very great. If this latter plan be resorted to, however, the depth of the wells must be considerable, to prevent a chance of the water tearing up the sand and exposing the foundations.

In Madras, however, when the wells are used to carry Bridge piers, it is usual only to sink them about 6 feet in the sand, the piers being connected together both at their up and down-stream ends by a line of wells acting as curtain walls, to prevent a scour; a flooring of masonry or concrete is also added between the piers, and a talus of loose stone is added on the down-stream sides beyond the lower curtain walls as a further protection against scour. This arrangement will be seen in the plan of the Markunda Bridge, under the Section BRIDGES. The total quantity of masonry employed is scarcely less than would be required to sink the principal wells to a depth well below any possible scour, but it is generally a cheaper arrangement, from the great expense of sinking them when the depth is great; unless, however, there is plenty of material on the spot available for the talus, the arrangement is not to be recommended.

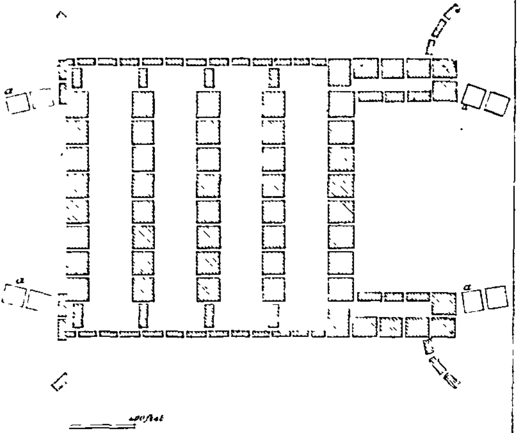
The wells being finished, may be filled in with brick or kunkur, arched over, and connected together by arches, on the top of which the superstructure is built, or they may be filled with concrete from the bottom, thus forming a series of solid cylinders.

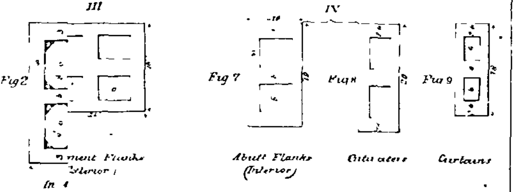
408. The following is a description of the Block foundations used in the Solani Aqueduct, on the Ganges Canal, by Lieut. (now Colonel) H. Yule, R.E., from the "R.E. Professional Papers." (*Vide Plates* LII. and LIII.)

The foundations of each pier consist of eight blocks of brick-work, measuring 22 feet by 20 in surface, and 20 feet in depth sunk flush with the level of the flooring of the waterway, at intervals of 2 feet 3 inches only. Each block contains four shafts or wells, in which the excavation was carried on in the manner already described.

The principal blocks of the abutments measure 26 by 22 feet superficially. Those supporting the wings of the abutments are of various inferior sizes.

There is also a small block at each end of every pier supporting the cut-waters; and




III
IV
Fig 2
Fig 7
Fig 9
Abutt Flanks
(Interior)
Curtains

a line of almost contiguous blocks forms a protecting curtain for the whole length of the bridge, on both up-stream and down-stream sides. The whole of these are sunk to a depth of 20 feet.

For the convenience of accounts, these foundation-blocks, whilst in progress, were divided into four classes, according to size; the first class embracing the large blocks of the abutments; the second, those of the piers and ends of abutments; the third, those on the exterior flanks of the abutments; and the fourth, all the smaller blocks having only two shafts. The total number of blocks is as follows:—

First class, ...	20
Second „	120
Third „	12
Fourth „	142
Total, ...	294

containing, when completed, about 1,700,000 cubic feet of brickwork. In this are not included a number of other blocks connecting the abutments of the aqueduct with the walls which inclose the earthen embankment across the valley. The position of these is shown by the unshaded blocks.

In commencing the foundations of a pier, the sand was dug out within an inch or two of the water-level, and the position of the eight principal blocks marked off accurately from the axis of the aqueduct. Curb-frames of whole timbers, running generally from 10 to 13 inches square were then laid down, levelled, and built on to a height of 12 feet. In building, five bonds of hoop-iron were laid in every foot of height, this way and that way alternately. The process of undersinking was then commenced, and the block sunk flush with the water. The remaining 8 feet of masonry was then added, but without the use of hoop-iron, and when completed, undersinking was renewed till the full depth was attained.

In the first blocks which were built, the wells were octagonal in plan from bottom to top. But from a growing conviction that this form, though adding to the mass of masonry, added nothing to its strength, from its destroying the bond of the brickwork, and inducing careless workmanship, first the *upper* part of the blocks was built with rectangular shafts, and latterly the entire blocks were so constructed. Skew-backs were left near the top of every well for a three-brick arch to vault it over, as well as on the exterior of each block in order to connect it with that adjoining; so that the foundation of a pier, when finished, presented a solid and continuous platform of brickwork, measuring 192 by 20 feet.

The lime used was derived from the limestone boulders gathered in the bed of the Ganges and its tributaries; the mortar employed consisting of a mixture of lime and pounded brick, in the proportion of two-thirds of the latter to one-third of the former. [illegible] excavation on the lower side. In a few instances, from working the *jham* (*vide* p. 404) too much towards the exterior of the larger walls, rents occurred in the masonry, as if from the hogging or convexing of the curb-frame. As soon as these were perceived by the officer in charge, the work was directed vigorously towards the centre of each block, which always had the effect of completely re-closing the fissures.

Though the boring had given no result but sand to a depth of 32 feet, yet under some of the piers, thin local beds of clay and mud were met with. These occasioned

great delay, as in such places the extraction of hundreds of cubic feet of soil scarcely affected the level of the blocks a hair's breadth. This was most especially the case with the foundations of the pier first undertaken. The large timbers on the outside of the curb, instead of being halved into each other, so as to form a flush frame, were only checked into one another 1 inch either way, and strongly bolted ; and the hollow spaces thus left under two of the four sides of the curb frame, happened to be turned to the outer side of the pier, that is towards the waterway of the adjoining arches, without any anticipation of evil consequences. The result appeared to be that the curb-frames continued to rest nearly unmoved on the lower beams *cc*, whilst the spaces under *bb* formed bridges, or open traps, through which a constant flow of mud took place to replenish the wells as fast as they were emptied by the *jham*. At last it was found necessary to inclose the most refractory blocks in sheet-piling, in order to complete the sinking.

The encounter with pieces of timber was also a serious obstacle. In a part of the work a species of coffer-dam had been formed to exclude floods, the piles of which had been at one point breached and submerged. Here these obstacles were not unfrequent, and were very troublesome when they lay athwart the wells at a considerable depth in the water. The best way to get rid of them was found to be by boring several contiguous holes through the timber, with a long auger, and then breaking it through by a violent blow with a heavy beam, after which there was little difficulty in removing the separate pieces.

The two-shafted blocks were not so easily guided in their descent. If they leaned over to one side, as they were very apt to do on account of the narrow base, it was exceedingly difficult to restore them ; one went suddenly to pieces, probably from a sudden falling in of sand and consequent fracture of the curb-frame, involving the loss of two lives, and forming a grievous obstacle to its replacement by another block. This was the only fatal accident on this branch of work during three years of its progress.

At the suggestion of Mr. Thomas Login, a young engineer assistant on the work, the experiment was tried of building these narrow blocks in the form of an inverted wedge, the side walls having a considerable batter on the outside. In this form these blocks preserved their upright position much better

The following Table shows the average, on a considerable number of blocks of the different sizes, of the daily progress in sinking by the process described :—

Class of foundation blocks.	No. of each affording the average.	Depth in feet: To which the first 12 feet of masonry had to be sunk	Depth in feet: Through which additionally the completed block had to be sunk	Entire depth in feet.	Average number of days occupied.	Average daily rate of sinking, in feet and decimals: For the first part of each block.	Average daily rate of sinking, in feet and decimals: For the completed block	Average daily rate of sinking, in feet and decimals: On the whole process
First class,	10	12 2	..	..	19·1	638	..	..
Second class,	4	12 127	..	..	15	88	..	..
Ditto, . .	10	14·063	8	22·063	57 4	694	·293	·384
Third class,	4	12 22	..	..	15·5	78	..	..
Ditto, . .	2	13 86	8	21 86	40 5	·692	·44	·54
Fourth class,	3	13·25	8	21·25	49	·678	·341	·43

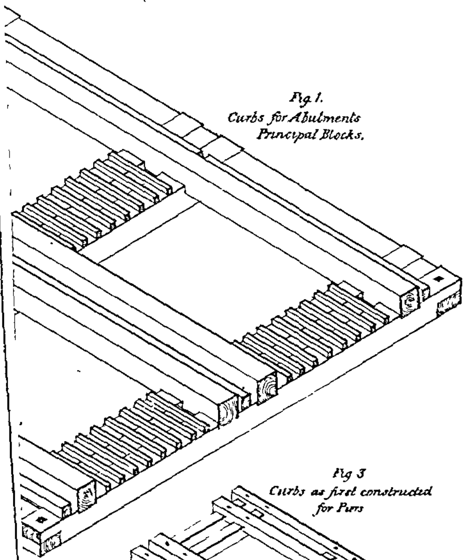


Fig. 1.
Curbs for Abutments
Principal Blocks.

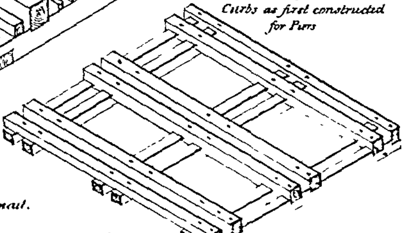


Fig 3
Curbs as first constructed
for Piers

Trenaut.

Scale 12 feet to an inch

feet deep on the sides parallel to the stream and on the down-stream side, and 10 feet deep on the up-stream side. All round the flooring outside the curtain blocks there should be thrown in boulders or brick-rubbish at 200 cubic feet to the foot run of curtain blocks where they are 20 feet deep, and 100 cubic feet to the foot run where they are 10 feet deep.

The general arrangement of this protection work is shown in the sketch on the preceding page.

The slopes of the Railway embankment joining the abutments should be pitched on both sides with brick or kunkur blocks, or boulders, for 100 yards, and a mass of such blocks should, besides, be accumulated round the end of the embankment where it joins the abutment, both on up and down-stream sides, to the extent of 50,000 cubic feet on each side.

410. Excavating apparatus.—As long as the water in the interior can be kept out by pumping or lifting, the work of sinking the wells proceeds quickly; but when the work has to proceed under water, it is very slow, and many different methods have been adopted to clear out the water and *core* of the wells.

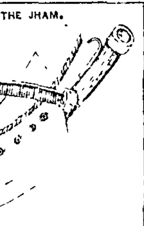
411. The Jham.—The simplest, and indeed the original Indian plan, is the use of a machine called a *jham*, which is a huge phowrah or hoe; a straight socket is cast on to it, in which a pole is fitted, and by which the *jham* when lowered into the water can be worked into the sand from a stage above. The pole is then withdrawn, and by means of a windlass and rope, the *jham* with its load of sand is dragged up, emptied, and again sent down. In some parts of the country, the well-sinkers dive every time and work the *jham* into the sand by their hands, and divers have generally to be employed in case of any obstruction to the regular descent of the well, (vide *Plate* No. LIV.)

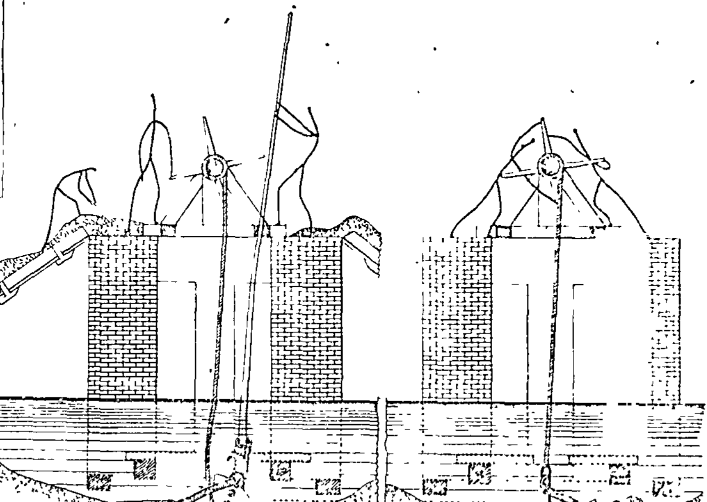
An improved form of *jham* is described in the next para., as used on the Jumna Bridge at Allahabad.

412. The following is a description of the Well foundations used for the Great Railway Bridge over the Jumna at Allahabad (from the "Civil Engineer's Journal," (vide *Plate* LV.)

The Jumna, like most of the Indian rivers, winds about much in its course, and varies in width and depth considerably; and within a distance of three-quarters of a mile above and below the railway bridge, it is 65 and 72 feet deep, respectively, at low water, but this depth is reduced to only 15 feet at the spot selected for crossing by the chief engineer, Mr. Edward Purser. A number of experimental brick cylinders were

WELL SINKING WITH THE JHAM.





sunk to ascertain what the bed of the river consisted of, and at a depth of 35 feet nothing but sand partly mixed with clay was found. Generally speaking the water is so low in the Indian rivers between the months of November and May, that there are no great difficulties to be got over in beginning operations for sinking the cylinders to form the foundations of the piers: but in the Jumna, which is never dry, it was unavoidable that the piers had to be begun where there was deep water: and as the means of pitching iron curbs under water were not at hand, the question arose, what was the best mode of commencing the building of the cylinders preparatory to sinking them?

The simplest plan seemed to be to form an artificial island for each pier; and this was done in the following manner:—Taking the centre of a pier in 15 feet depth of water as the starting point, and setting out a space of 175 feet length by 120 feet width, sand bags were sunk on the down-stream and two adjacent sides, thus forming three sides of an enclosure, in the centre of which loose sand was thrown, which was carried by the stream and deposited against the upper side of the lower boundary of sand bags, where it formed a ridge; in due course, the surface of the water was thus reached, when the sand was all thrown on the up-stream side, and an island was thereby speedily formed 100 feet long by 60 feet wide at the top. On this island the ten iron curbs were pitched to form the bases for the ten brick cylinders composing the foundations of the pier, being pitched at a distance of 15 feet 6 inches from centre to centre transversely of the pier, and 15 feet longitudinally.

The iron curb is shown in *Fig.* 7, which gives a vertical section of one of the brick cylinders to a larger scale, showing the cylinders AA partially sunk. The curb B is 13 feet 6 inches diameter outside, and 8 feet 6 inches inside, the interior of the brick cylinder diminishing to 6 feet 9 inches diameter. The curb consist of a flat horizontal ring of ½-inch boiler plate, 2 feet 6 inches wide, rivetted by an angle-iron to an outer cylindrical ring of similar plate 18 inches deep, and having gusset plates connecting the two rings underneath. The outer cylindrical ring extends 3 inches above the horizontal one, forming a support all round to the base of the brick cylinder on the outside; and an angle-iron upon the timber edge of the flat ring forms a similar support within. To keep the curbs in place they are sunk till the top plate, of the curb is bedded on the sand; then 12 feet height of brick-work, 3 feet 4½ inches thick, is built upon the curb, the first 5 feet of which are sunk by simply taking out the sand from the underside of the curb by hand, after which the *jham* must be used.

The results of numerous trials with many kinds and forms of the tool gave a *jham* such as is shown at C, in *Figs* 7 and 8. The *jham* is made of wrought-iron with a scoop 2 feet 2 inches wide, and 2 feet 4 inches long, made thin and sharp at the front edge, and supported by two stays fixed to the sides of the scoop, and also made thin and sharp at their front edges for penetrating the ground readily; the whole weighing about ¾ cwt.

The mode of using this *jham* is as follows:—By means of a couple of ropes, D, attached to the tail end of the arm E, the *jham* is lowered by hand to the bottom of the well, *till the cutting edge of the scoop C and the outer end of the arm E rest upon* the sand, as shown by the full lines in *Fig.* 7. Then with the weight of two or three men bearing on the top of the vertical pole F, which is held in place by the pin at the bottom passing loosely through a hole in the tail end of the arm E, the scoop is raised a short distance by the ropes D, the outer end of the arm resting upon the sand and

forming a sort of centre of motion; and the scoop is then dropped with the weight of the men bearing upon it, and its cutting edge is thus forced into the sand. By repeating these strokes the scoop is forced into the sand, the workmen knowing by the feel when the scoop is deep enough in the sand. Then with the *weight of the men still* on the vertical pole F, the *jham* is hauled up by means of the windlass G, round the barrel of which the chain is wound that is attached to the extremity of the arm E; the *jham* being thereby tilted into position is brought up filled with sand, as shown dotted in *Fig.* 7. It requires ten men at the windlass to move the *jham* when bedded and covered with sand; it is then drawn up to the top, when it is emptied, and the process repeated.

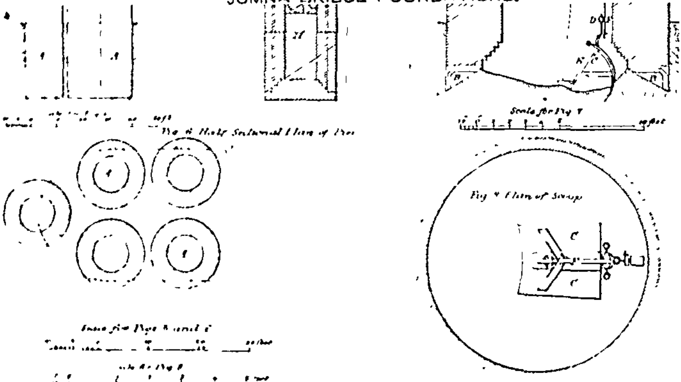
After the first length of 12 feet of brick cylinder had been sunk down to the water level, an additional 15 feet were added, as shown in *Fig* 5; and the process of sinking continued till the 15 feet added had been sunk, when an additional 16 feet were added, making a total of 43 feet depth. As a precaution for preventing the curb and lower portion of the brick cylinder from parting from the upper portion, which was found sometimes to occur, provision was made on the curb for attaching six holding up bolts, which were built into the brickwork for a length of 16 feet, as shown in *Fig.* 5, and at intervals of every 5 feet, a ring of flat iron was dropped over all the bolts and cottered down on to the brickwork

The rate of sinking of the cylinders was far from regular, at starting, the progress was pretty even, the cylinders going down from 15 to 9 inches per day; but the average rate of sinking when down to 20 feet was not more than 4½ inches per day; and beyond that depth, the rate of progress gradually decreased till it was not more than 1½ to 1 inch per day of 24 hours. The plan that was adopted where the sinking went on slowly was to add extra weight on the top of the cylinder, either by building extra brickwork, or adding a load of rails. In very bad cases both means were used, till a weight of 40 tons on each cylinder was added; and even with this additional load on the top, great difficulty was met with when the sinking had reached a depth of 40 feet; which is not surprising when it is considered that there was then a constant pressure due to 40 feet head of water acting upon the sand round the exterior surface of the cylinder at the bottom.

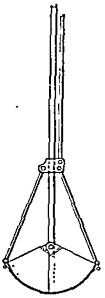
When the cylinders were got down to the depth of 43 feet they were ready for the concrete H, *Fig.* 5; but before throwing in the concrete, a diver supplied with Siebe's diving apparatus was sent down to clear away any rubbish that might be left at the bottom of the well, and level the space under the curbs for the reception of the concrete. A depth of 15 feet of concrete was then thrown in, composed of 1 part of fresh-burnt unslaked lime, 1 of broken bricks, and 2 of underburnt lime; these were the usual proportions of the concrete used in stopping the cylinders, and about 18 days were generally allowed for it to set. A disc made of two thicknesses of 2 inch planking was let down upon the surface of the concrete, weighted by 3 feet thickness of brick-work; this disc was a little less in diameter than the inside of the cylinder, so as to pass freely down on to the concrete, the space between the edge of the disc and the sides of the cylinder being then filled in with wood wedges driven by divers. The object of putting in this disc was *to prevent the concrete being disturbed by the* pressure of water underneath, whilst the water was being baled out from above the concrete, preparatory to building the cylinder up solid.

The mortar used was made of 1 part of lime to 1 or 1½ parts of soorkee, which

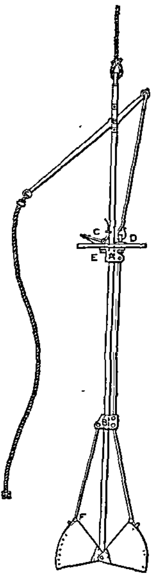
JUMNA BRIDGE FOUNDATIONS.



5th.—There are also two stops on the spear, and a spring clasp, C, to keep the jaws open while the scoop is being lowered.



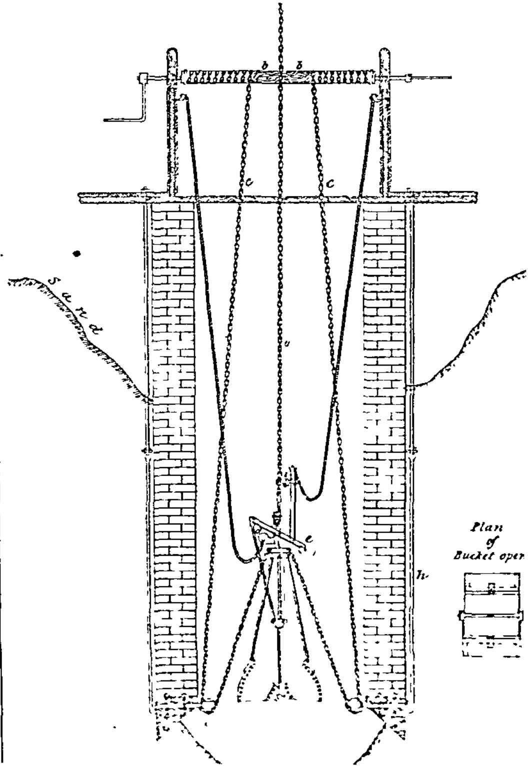
The action is very simple. The machine is slung over the well or block by tackle and pulleys worked by a windlass, from any convenient form of staging; it is lowered, with the jaws in the open position, till it rests on the bottom; the two attendants step on the platform, and one with his foot releases the spring clasp; the windlass men at once wind up, but the weight of the men keeps the scoop from rising till the jaws have closed and it is full of sand; then all rise together; the two men step off on the sides of the well, and, as the full bucket rises to the level, they sway it over a wooden platform at the side, and pull smartly at the lever; the jaws open, and the catch holds them; so the sand falls out on the platform; the machine swings back, and is immediately lowered again, while the sand is shovelled or run away. This can be repeated at the rate of one lift per minute, lifting $1\frac{1}{4}$ to $1\frac{1}{2}$ cubic feet each time.



414. *Deep-Well Excavator.*—The action of this Excavator is in every respect similar to that of Fouracres' ordinary Excavator for small wells with this exception, that the process of closing the scoops of the Excavator is performed by two chains and a windlass, instead of by actual pressure by men's weight. The Excavator is lowered into the well, in the position shown in the drawing (*Plate* LVI.,) by the chain *a*, the end of which is attached to a windlass in any convenient position: as the men lower the chain *a*, those at the windlass *b* wind up the chains *c* which become loose as the Excavator descends; when the Excavator reaches the

FOURACRE'S PATENT DEEP-WELL EXCAVATOR.

(In use on the Soane Anicut)



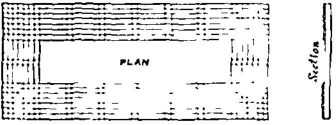
bottom of the well, the catch d is released by means of the rope attached to it, and the scoops are closed by tightening up the chain c, which draws down the collar f, and locks the scoops upon the earth; when the Excavator has taken its load, the men at the windlass attached to the chain a, wind it up, and those at the windlass h wind the chain, so that the Excavator is free to rise; when the machine reaches the top of the well it is swung over the side, and the load released by opening the scoops with the lever e, which is hinged to render the machine more handy; when lowered into the well a small iron keeps the lever in position to prevent it fouling the side of the well.

The pulleys marked g through which the chain comes, are put on to the well when the earth is first laid; the two poles outside, marked k, keep the pulleys in their places, while the well is being sunk and also tie the well together, to prevent the lower part falling in; they also keep the windlass h on the top of the well firmly in its place; when the well is sunk to the full depth, the outer poles are driven down clear of the hook; the pulley can then with very little trouble be extricated from the earth, for it only fits loosely into wood, the stump pole can then be drawn.

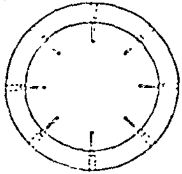
415. *Self-Closing Deep Well Excavator.*—The Excavator is lowered into the well in the position shown by the dark-lined portion of the drawing, *Plate* LVII., with the exception that the diagonal arms marked b are kept up in the position shown by the dotted lines until the scoop of the Excavator takes the ground; when the scoop is resting on the ground, the arms (b) are lowered by means of the rope (c), until they are in the position shown by the dark-lined portion, when the Excavator is thus fixed as it were at the bottom of the well, for it is evident that the collar a, (which is firmly riveted to the main rod of the Excavator,) is completely prevented from moving by the compression of the diagonal rods b upon it the catch marked d is liberated by pulling the rope attached to it, when this is done the men at the windlass commence to wind up the main chain, which, being passed round the pulley e, and fastened to the collar a, draws down the collar i, and so presses the scoops of the Excavator into the ground; at the same time the cross head f, attached to the main chain rises with it, and as it rises it lifts the ring and chain g; the length of this chain is so adjusted, that at the same time as the jaws are closed, the tension of the chain g draws away the diagonals b from the side of the well, and when this is done the whole machine is free to rise with the load.

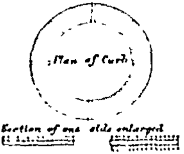
When the Excavator is lifted to the top of the well it is swayed over the side, *and a chain attached* to the scaffolding, which has been previously adjusted to the correct length, is hooked into the hook *h*; the men at the windlass then lower away, and as the chain attached to the hook becomes tightened, the weight of the Excavator causes the scoops to open and discharge their load, and at the same time the machine is re-set ready for lowering into the well.

416. The *well curbs* used on the Dehree Division were of a new description, and while being very inexpensive, were found sufficient for the purpose. The curbs were simple platforms of small solid hill bamboos, laid close side by side, well lashed at the corners, and with under cleats of short lengths lashed on for strengthening. All crevices were stuffed with grass, and care taken that no bamboos projected beyond the masonry.



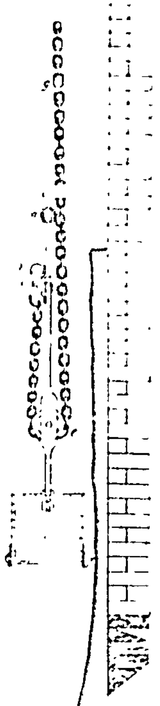
When round wells are to be sunk, the bamboo curb is thus made:—





A mould wheel of timber about 9 inches by 4 inches is prepared, whose inside diameter is the outside diameter of the curb; holes are pierced through this to receive short pieces of solid hill bamboos, projecting inward by the breadth of the curb; these are wedged in; similar bamboos, split in two, are now coiled round and round (the mould wheel being supported 2 feet above the ground), and lashed to the bamboos till the required breadth is attained, when the whole is sawn out. If greater

Side Elevation



stiffness is needed, bamboos can be coiled both above and below the cleats; in fact a wedge-shaped curb could be made. But the single bamboo has been found sufficient to sink wells 6 feet in sand without cracking.

The cost of these curbs is about as follows:—

	RS.	A.	P.
1. Oblong block, 10½ by 6 feet 18 inches walls—			
40 bamboos, small, ...	0	5	0
String, ...	0	2	0
Labor, ...	0	2	0
	0	9	0
2. Circular wells, 5 feet inside, 6½ out—			
20 bamboos, ...	0	2	6
String, ...	0	2	0
Labor, ...	0	2	0
	0	6	6

417. Bull's Hand Dredger (vide *Plate* LVIII).—A short chain four feet long, with a ring in the centre, should be attached by its ends to the rings on the chains working the machine. To the centre ring the chain for lowering and raising the machine is to be fixed, of a length greater or less according to the depth of the well. On the well two bullees should be fixed, with an iron block made fast to the junction. The bullees should not be less than 10 or 12 feet in length, stayed on either side to the ground. A wooden platform 6 feet × 4 feet composed of 1 inch sál planks made fast to two under cross pieces, is also required, and two ¾-inch ropes, one made fast to the key keeping the jaws of the machine open, and the other to the centre ring in the short chain first-mentioned.

In working, the machine is opened on the wooden platform and the key fixed. It is then lowered into the well, and on reaching the bottom the key is withdrawn; the rope attached to the latter should be coiled on one side of the platform ready for use. *A gentle pulling-and-giving motion* should now be applied with the rope attached to the centre ring of the short chain, *slowly at first,* and *as this peculiar motion causes the jaw of the machine to sink or cut into the sand, the strain should be increased,* till there is no further yielding to the pull which two men can put on the rope. The machine should then be raised and landed on the wooden platform. The operation of re-setting it, for lowering, releases the subsoil brought up, and saves all trouble in emptying.

The average quantity brought up, when the machine is properly worked, is 2 cubic feet; and in a well of 12 feet 6 inches diameter, 38 feet deep, there is no difficulty in working it 25 times in an hour.

Three men on the top of the well, (not including those employed in removing the sand, which is best done by contract,) and 15 men to pull, are required to work the hand dredger. The average performance per day in a 12 feet 6 inches well is 3 feet of sinkage for regular work; and *practically speaking the depth of the well is of no consequence*, the difference of time taken by the coolies walking 10 or 50 feet being inappreciable as compared with the time taken by each operation.

The dredger is principally intended for working in sand, but brings up anything which is cut up so that it can grip it. The motion of the wells being constant, they should not require weighting; and up to 35 feet, it has not been found necessary to weight the well.

This dredger is used extensively on the large bridges of the Oudh and Rohilcund Railway, and for the Punjab Northern State Railways in preference to any form of excavator.

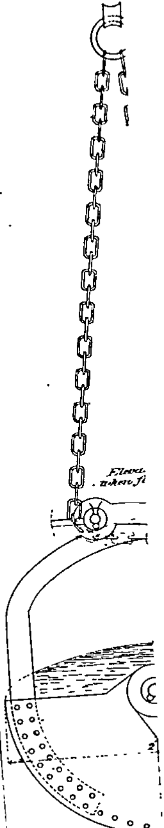
418. WEBB'S SUBAQUEOUS EXCAVATOR.—In the Madras Railways another form of Excavator (as illustrated in *Plates* LIX. and LX.,) somewhat similar in principle to Fouracre's and Bull's, has been used with *great success*.

The excavator is a cylinder, from which about a fourth part is removed, to form horizontal and vertical cutting edges *a*, *b*, in both Plates. It is formed of boiler plate riveted to angle iron framing. On top are two iron catches C, D, which receive the wrought-iron bow E; this slides up and down the square guide bar F.

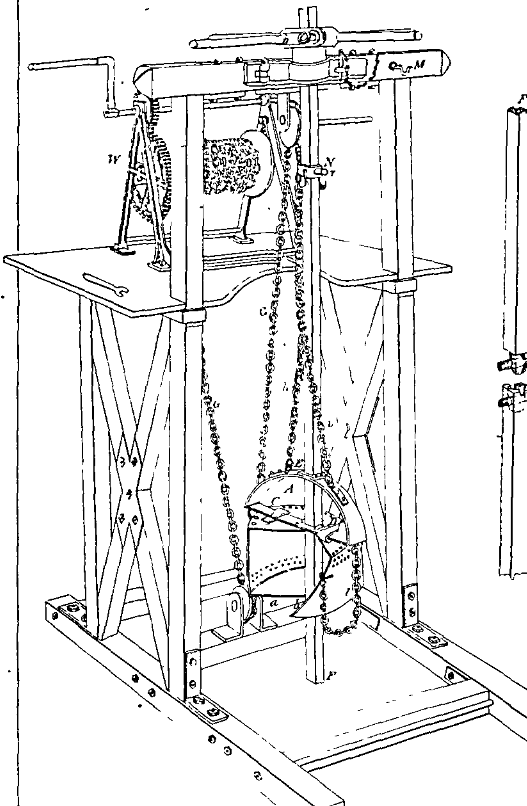
To the upper side of this bow the hoisting chain G, is attached by short pieces *h*, *i*, while underneath a pair of short chains *k*, *l*, connect it with the excavator.

The *square bar* F, by means of which the excavator is turned and guided in its ascent and descent, together with its capstan, crab-winch, and framing, all clearly shown in the drawings, complete the apparatus. The guide bar F is made in convenient lengths, connected by the joint X, and carries a sliding collar N, which can be clamped at any part of it, by means of a pinching screw *r*.

On each side of this collar a hook is rivetted for the purpose of supporting the hoisting chains G, when disconnected.



WEBB'S SUBAQUEOUS EXCAVATOR.



The hoisting chain is provided with special links every six feet, which allow of its separation at them.

The mode of using the excavator is as follows:—The frame is placed as shown in *Plate* LIX., over the cylinder or well to be sunk, and the bar F dropped to the bottom of it. The crab barrel is then thrown out of gear, which allows the excavator to descend by its own weight, being guided in its descent by the bar F, which passes through the bow E: as soon as it reaches the bottom of the well, the hoisting chain G is disconnected at one of the links provided for the purpose, the upper part leading from the winch being hooked to the frame at M, while the lower part which is connected with the excavator is hooked to the collar N: this allows the excavator to be turned without getting the chain G twisted round the bar; the men at the capstan then give a few turns from right to left, which fills the excavator (five turns are generally sufficient to do so). A quarter turn of the capstan in the opposite direction releases the bow E from the excavator, which remains embedded in the material being excavated; the chain G is now unhooked at N, M, and joined up as before, and the bow E drawn up by turning the winch W; as soon as it is raised to the extent of the chains *k*, *l*, it lifts the excavator, and at the same time tilts it as shown in *Plate* LX., in which position it is drawn to the top and emptied into a truck provided for the purpose; or to save time, the full excavator may be removed, and an empty one hooked on to the chains *k*, *l*; so that when this comes up full, the former one will be ready to take its place, to be again lowered and filled.

The inventor states that the most useful sizes are 1 foot 6 inches diameter by 9 inches deep, and 2 feet diameter by 1 foot deep (the former size being suited to hard material, such as stiff clay, &c., and the latter to softer stuff, as mud, sand, &c.): that this excavator will raise per day on an average, 60 cubic feet of hard material, such as stiff clay and laterite gravel, from a depth of 50 or 60 feet below water, *when worked exclusively by men*: that this rate may be increased to 180 cubic feet per day, if a steam crab or hoist be used; and that probably double these quantities of soft stuff would be raised. Six men are sufficient to work this machine.

The inventor further says, that the cost of the excavator complete with frame, crab, chains, &c., would be about Rs. 300, and a royalty of £50 per annum for the use of each machine will be charged.

The cost of a steam winch 4-horse power with boiler and steam fittings complete would be about Rs. 1,800. Assuming these data, the cost of working would be, as under:—

By Manual Labor.

	RS.	A.	P.
6 Men, at Rs. 0-6-0 per day,..	2	4	0
1 Mistry, at Rs.	1	0	0
Wear, depreciation of machinery, repairs at 25 per cent per annum on value, Rs 300, ...	0	3	10
Royalty on patent, Rs. 500 per annum, ...	1	9	7
Cost per day, ... Total,	5	1	5

for 60 cubic feet excavated, or a rate of Rs. 0-1-4 per cubic foot = Rs. 2-4-0 per cubic yard.

By Steam Power.

	RS.	A.	P.
1 Engine driver, at Rs. 1 per day, ...	1	0	0
1 Stoker, at Rs 0-8-0, ...	0	8	0
7 Men coolies, at Rs. 0-4-0, ...	1	12	0
2¼ Cwt. coal, at Rs. 30 a ton, ...	3	12	0
¼ lb. Oil, ...	0	2	0
25 Per cent. on Rs. 2,100 for wear, depreciation, and repairs of machinery, ...	1	10	10
Royalty on patent, ...	1	9	7
Cost per day, ... Total,	10	6	5

Quantity excavated 180 cubic feet, or a rate of Rs. 0-0-11 per cubic foot, or Rs. 1-8-9 a cubic yard.

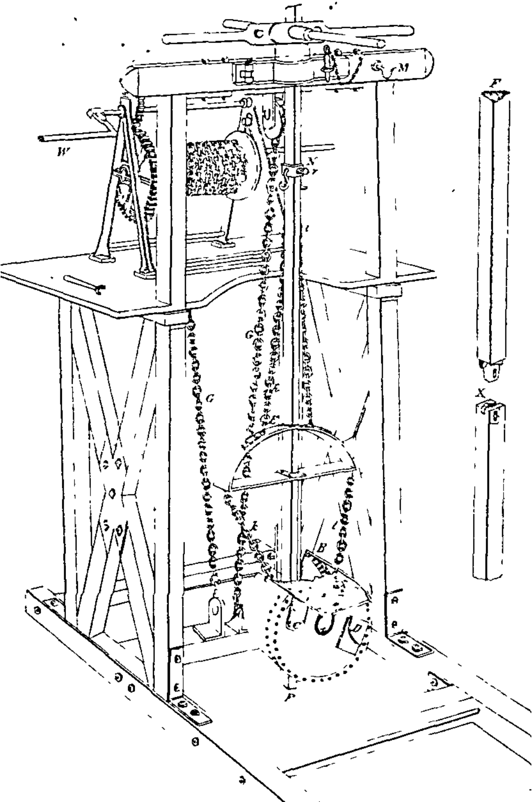
If wood fuel be used, the cost would be for fuel 7¼ cwt., at Rs. 3 per ton = Rs. 1-2-6. This would reduce the cost of working to Rs. 7-12-11 a day = Rs. 0-0-8 per cubic foot, or Rs. 1-2-0 per cubic yard.

This excavator had a prolonged practical trial in sinking the Iron Cyinder foundations for the Kudlahoondy Bridge, Madras Railway. Twenty-six cylinders 6 feet diameter, were sunk by means of these excavators to depths of from 37 feet to 65 feet below the water level,

through 2 feet of mud.
" 10 " sand.
" 25 " blue clay.
" 15 " laterite gravel, very hard.
" 3 " decayed granite.

The above trial proves beyond doubt its practical value.

WEBB'S SUBAQUEOUS EXCAVATOR.



419. SAND PUMP (vide *Plate* LXI).—A machine called the *Sand pump* has of late years been much employed, chiefly on the large Railway Bridges, which is decidedly superior to the *jham*, especially when the depth of sinking is great; but it is not preferred by all Engineers to the excavators and hand dredgers above described.

It consists of a cast iron-cylinder 3 feet in diameter and 2 feet high, closed at top with an air-tight cover, in which are several holes fitted with leather or indian-rubber valves opening upwards. Above this cover is a smaller cast-iron cylinder, 1 foot long, and 10 inches in diameter, in which is a leaden piston which works easily up and down, having four valves in it, also opening upwards. This piston is worked by a rod 2 feet long, having an eye on the upper end for the pumping tackle.

The large cylinder has also a bottom cover, which is however removable, and to the centre of which is fitted the suction pipe, as shown in the drawing. This cover is held in its place by lugs fastened with cotter pins. On the lower part of the pipe, radiating cutters are now generally fixed, made of ½-inch plate iron, sharpened and steeled at the edge, and 9 inches deep.

In working—the pump is lowered to the bottom of the well by means of tackle connected with eyes cast on the sides of the large cylinder. If anything hard is met with, the pump can be lifted about 4 feet, and jumped up and down until the cutters have broken it. When once fixed in the sand, the piston of the pump is worked up and down by means of a rope and pulley, until the resistance shows that the larger cylinder is full, or nearly so, of sand and water, when the pump itself is raised to the surface. Then one of the trollies, which work on a tramway, being run over the centre of the pier, receives the pump. The cotter pins are then knocked out, and the lugs turned round—the body of the pump is lifted, and the bottom is left on the trolly with its load of sand. The trolly is then pushed away, another run under with a spare bottom, which is fitted, and the pump descends while the first bottom is being cleared out.

The pumps can be lowered and raised either by a gang of men working by an ordinary pulley and chain; or, what is better, by a steam hoist.

The work done by means of these sand pumps is very greatly in excess of what can be done by the ordinary *jham*, especially when the depth of water is great. On the Delhi Railway where they were in extensive use, the 12½ feet diameter masonry wells, which form the pier foundations to

the bridges, have been sunk, 40 feet through sand and water, with an intervening stratum of clay 6 feet thick and 16 feet from the surface, and a depth of 3 to 7 feet has been constantly achieved in one day. The pumps will also lift bricks and stones if not too large for the suction pipe.

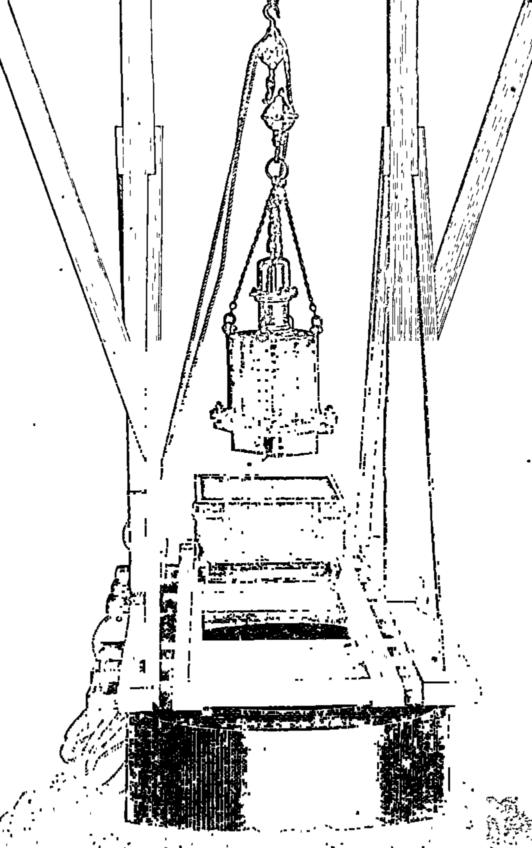
420. Foundations in Water.—In laying foundations in water, two difficulties have to be overcome, both of which require great resources and care on the part of the engineer. The first is found in the means to be used in preparing the bed of the foundation: and the second, in securing the bed from the action of the water, to ensure the safety of the foundations. The last is, generally the more difficult problem of the two; for a current of water will gradually wear away, not only every variety of loose soils, but also the more tender rocks, such as most varieties of sand-stone and the calcareous and argillaceous rocks, particularly when they are stratified, or are of a loose texture.

To prepare the bed of a foundation in *stagnant* water, the only difficulty that presents itself is to exclude the water from the area on which the structure is to rest. If the depth of water is not over 4 feet, this is done by surrounding the area with an ordinary water-tight dam of clay, or of some other binding earth. For this purpose, a shallow trench is formed around the area by removing the soft, or loose stratum on the bottom; the foundation of the dam is commenced by filling this trench with the clay, and the dam is made by spreading successive layers of clay about one foot thick, and pressing each layer as it is spread, to render it more compact. When the dam is completed, the water is pumped out from the enclosed area, and the bed for the foundation is prepared as on dry land.

421. Coffer-dam.—When the depth of stagnant water is over 4 feet, and in *running* water, of any depth, the ordinary dam must be replaced by the *Coffer-dam.* This construction consists of two rows of planks or *Sheeting piles,* driven into the soil vertically, forming thus a coffer work, between which clay or binding earth, termed the *Puddling,* is filled in, to form a water-tight dam to exclude the water from the area enclosed.

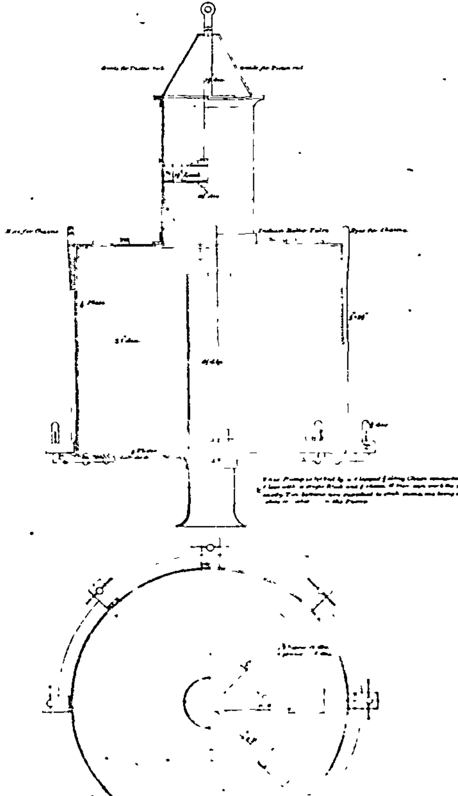
The arrangement, construction, and dimensions of coffer-dams depend on their specific object, the depth of water, and the nature of the subsoil on which the coffer-dam rests.

With regard to the first point, the width of the dam between the sheeting piles should be so regulated as to serve as a scaffolding for the machinery and materials required about the work. This is peculiarly requisite



SAND PUMP

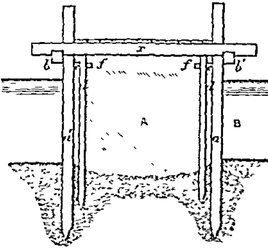
As used at the Beas Bridge Works—Delhi Railway.



where the coffer-dam encloses an isolated position removed from the shore. The interior space enclosed by the dam should have the requisite capacity for receiving the bed of the foundations, and such materials and machinery as may be required within the dam.

The width, or thickness of the coffer-dam, by which is understood the distance between the sheeting piles, should be sufficient not only to be impermeable to water, but to form, by the weight of the puddling, in combination with the resistance of the timber work, a wall of sufficient strength to resist the horizontal pressure of the water on the exterior, when the interior space is pumped dry. The resistance offered by the weight of the puddling to the pressure of the water can be easily calculated; that offered by the timber work will depend upon the manner in which the framing isarranged, and the means taken to *stay* or buttress the dam from the enclosed space.

422. The most simple and the usual *construction of a coffer-dam* consists in driving a row of ordinary straight piles (*a*) around the area (B) to be enclosed, placing their centre lines about 4 feet asunder. A second row (*a'*) is driven parallel to the first, the respective piles being the same distance apart; the distance *a a'* between the centre lines of the two rows being so regulated, as to leave the *requisite thickness between* the sheeting piles for the dam.



The piles of each row are connected by a horizontal beam of square timber, termed a *string* or *wale piece*, *b*, *b'* placed a foot or two above the highest water line, and notched and bolted to each pile. The string pieces (*b'*) of the inner row of piles is placed on the side next to the area enclosed, and those *b* of the outer row on the outside. Cross beams *x* of square timber connect the string pieces of the two rows, upon which they are notched, serving both to prevent the rows of piles from spreading from the pressure that may be thrown on them, and as a joisting for the scaf-

folding. On the opposite sides of the rows, interior string pieces *cc* are placed, about the same level with the exterior, for the purpose of serving both as guides and supports for the sheeting piles. The sheeting piles *d, d*, being well jointed, are driven in juxtaposition, and against the interior string pieces. A third course of string, or *ribbon* pieces *f, f*, of smaller scantling confine, by means of large spikes, the sheeting piles against the interior string pieces.

As has been stated, the thickness of the dam and the dimensions of the timber of which the coffer work is made, will depend upon the pressure due to the head of water, when the interior space is pumped dry. For extraordinary depths, the engineer would not act prudently were he to *neglect to verify by calculation the equilibrium between the pressure and* resistance; but for ordinary depths under 10 feet, a rule followed is to make the thickness of the dam 10 feet; and for depths over 10 feet to give an additional thickness of one foot for every additional depth of three feet. This rule will give every security against filtrations through the body of the dam, but it might not give sufficient strength unless the scantling of the coffer work were suitably increased in dimensions.

423. The main inconvenience met with in coffer-dams arises from the difficulty of preventing leakage under the dam. In all cases the piles must be driven into a firm stratum, and the sheeting piles should equally have a firm footing in a tenacious compact sub-stratum. When an excavation is requisite in the interior to uncover the subsoil on which the bed of the foundation is to be laid, the sheeting piles should be driven at least as deep as this point, and somewhat below it if the resistance offered to the driving does not prevent it.

The puddling should be formed of a mixture of tenacious clay and sand, as this mixture settles better than pure clay alone. Before placing the puddling, all the soft mud and loose soil between the sheeting piles should be carefully extracted; the puddling should be placed and compressed in layers, care being taken to agitate the water as little as practicable.

With requisite care, coffer-dams may be used for foundations in any depth of water, provided a water-tight bottoming can be found for the puddling. Sandy bottoms offer the greatest difficulty in this respect, and when the depth of water is over 5 feet, extraordinary precautions are requisite to prevent leakage under the puddling.

424. *Scotce Coffer-dam.*—The following is the Specification for the

coffer-dam used for laying in the foundation on the Seotee Bridge, Great Deccan Road:—

Half a mile above the site of the bridge the bed of the river consists entirely of sand-stone rock, which is considerably broken up and thrown about in masses. At site the bed, to a depth of 4 feet, is of sand and *budgeree*, laying on a stratum of blue loam of density and tenacity gradually increasing with the depth. At 10 feet the soil is firm and tenacious and can be trusted. The dry weather stream is about 12 inches deep.

The reason for selecting coffer-dam instead of well or block foundations in this case, is the high probability of meeting with large boulder stones or slabs of the sand-stone rock from up-stream, bedded at a depth below the surface, which would interfere greatly with the sinkage of the blocks, and probably altogether frustrate any attempt at obtaining a secure foundation by those means.

The nature of the substratum, moreover, while it affords facilities for the construction of a coffer-dam, would cause much labor to the well-sinker.

The coffer-dam will consist of a single line of sheet-piling driven and secured as hereafter shown for the foundation of one of the piers.

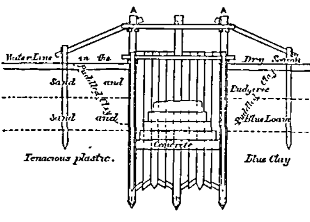
The timber for the piles to be of sál wood, to be carefully selected, straight-grained, free from knots and ring shakes.

The gauge piles alone will be rung with an iron hoop 3 × ¼ inches; these will also be shod with cast-iron shoes of the form shown in the diagram, with a square abutment for the pile to rest on.

The sheeting-piles will not be shod, but the end will be cut with an inclined edge to give the pile a drift towards the next pile. The sheeting piles will all be carefully fitted to each other before driving to ensure close contact.

The wedge piles will be tapered 2 inches in a regular taper for the lower 6 feet, the sides of the upper 9 feet being left parallel.

The space to be inclosed is in the clear 43 × 10 feet within the sheeting. Each



long side will be divided into 6 equal bays, 6 feet 5 inches long each; and each end

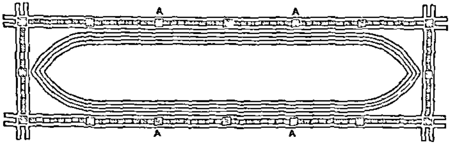
into 2 bays of 4 feet 5 inches each, by gauge piles 9 inches square, driven 17 feet below the water line, and standing 5 feet 6 inches above it.

The sheet piles will all be 9 inches by 4 inches, and driven 15 feet below the water line, with their heads 1½ feet above the water line.

When the gauge piles are driven to their proper depth, two rows of temporary double walings 6 inches by 4 inches, will be bolted on; the upper one to be 4 feet above the water line, and the other as low as it can be fixed, but not within 4 feet of the upper. The wales will be fixed to the gauge piles by ¾-inch iron bolts and nuts.

The sheet piles to fill up the bays are to be driven truly, and each bay keyed in with a wedge pile to make the dam water-tight.

When the piles are all driven, behind each gauge pile and at 8 feet distance from it, on the outside, a pile 6 × 6 inches will be driven 10 feet, its head standing 1½ feet above the water line. Through mortises in the head of this and of its corres-



ponding gauge pile, a piece of 2½ × ¾ inches flat bar iron will be passed, through slots in which wedge keys will be driven, against iron plates laid against the piles.

A shore of timber 6 × 6 inches will be laid across between the heads of the pair of gauge piles, AA, on each side of the centre of the dam.

The excavation will then be commenced, and having cleared 5 feet, the upper row of wales will be taken off and fixed at that depth against the inside of the dam, spurred and strutted across to add to its stiffness.

As the excavation proceeds the water will be baled out, and the seams between the piles will be well caulked and payed with oakum and tar.

Simultaneously with the interior excavation, and carried on with it to equal depths, the soil will be removed from the outside to as great a depth with a limit of 10 feet below water line as possible. This will be filled with puddled clay. It is expected that if the exterior can be thus cleared to a depth of 7 feet below water, there will be no difficulty in laying the interior of the dam nearly dry.

When the interior excavation has reached 10 feet below the water line, and been brought to a level, a bed of concrete 12 inches thick will be carefully laid in, the dam having been previously permitted to fill with water. The concrete will be carefully lowered in baskets, and be brought *to a level on its surface. This will be allowed to* lie undisturbed until thoroughly set, which should occur in 20 days, when the water will be thrown out, and the construction of the foundation proceed in stone laid in cement.

As the masonry rises, good strong clay will be rammed in round the work, so as completely to fill the space between the dam and the pier.

As there would be danger of disturbing the bed by drawing the piles, they will be cut off on completion of the work at 6 inches below the water line.

425. CAISSON.—When the depth of water is great, or when, from the permeability of the soil at the bottom, it is difficult to prevent leakage, a coffer-dam may be a less economical method of laying foundations than the caisson. The *Caisson* is a strong water-tight vessel having a bottom of solid heavy timber, and vertical sides so arranged, that they can be readily detached from the bottom.

A bed is prepared to receive the bottom of the caisson, by levelling the soil on which the structure is to rest, if it be of a suitable character to receive directly the foundation; or by driving large piles through the upper compressible strata of the soil to the firm stratum beneath. The heads of the piles are sawed off on a level to receive the bottom of the caisson.

426. It is essential that the bed shall be level, otherwise the cross strain on the unsupported parts of the timbers, leads to fractures and dangerous movements in the superstructure, as in the well known case of Westminster Bridge. In hard ground which cannot be levelled, and where piles (as suggested above) cannot be used, a bottomless caisson should be used, lined with tarpaulin allowed to adapt itself freely to the form of the bed, and béton can then be lowered to the bottom (as described in para. 128, of the Chapter on Limes and Concretes). The loose tarpaulin lining is essential to protect béton while filling up all the inequalities of the bed from the *washing* action of the water, before it has had time to set. If the hard, uneven bed be thus levelled, and floored with béton, the foundations may be carried up within the caisson with masonry, brick-work, &c., as preferred.

427. If, however, an ordinary caisson with a timber bottom be used, before settling it on its bed, it must be floated to and moored over it; and the masonry of the structure is commenced and carried up, until the weight grounds the caisson. The caisson should be so contrived, that it can be grounded, and afterwards raised, in case that the bed is found not to be accurately levelled. To effect this, a small sliding gate should be placed in the side of the caisson, for the purpose of filling it with water at pleasure. By means of this gate, the caisson can be filled and grounded, and by closing the gate and pumping out the water, it can be set afloat.

After the caisson is settled on its bed, and the masonry of the structure

431. Calculation of Stability.—The calculation of the stability of a retaining wall divides itself into two parts.

1st.—The thrust of the earth to be supported.

2nd.—The resistance of the wall.

The line of rupture is that along which separation takes place in case of a *slip* of earth (*see* BE, *Fig.* 2). The slope which the earth would assume, if left totally unsupported, is called the *natural slope* (BF), and it has been found that the line of rupture generally divides the angle formed by the natural slope and the back of the wall when vertical, into nearly equal parts.

The centre of pressure is that point in the back of the wall, above and below which there is an equal amount of pressure; and this has been found by experiment and calculation to be at two-thirds of the vertical height of the wall from its top.

Amount and Direction of the Thrust—The real thrust of any bank will depend on a variety of conditions which it is impossible to reduce to calculation: for, although we may by actual experiments with sand, gravel, and earths of different kinds, obtain data whence to calculate the thrust exerted by them in a perfectly dry state, another point must be attended to when we attempt to reduce these results to practice, viz., the action of water, which, by destroying the cohesion of the particles of earth, brings the mass of material behind the wall into a semi-fluid state, rendering its action more or less similar to that of a fluid according to the degree of saturation.

The tendency to slip will also very greatly depend on the manner in which the material is *filled in* against the wall. If the ground be *benched out* (*see Fig.* 1), and the earth well punned in layers inclined *from* the wall, the pressure will be very trifling, provided only that attention be paid to surface and back drainage. If on the other hand, the bank be tipped, in *the manner too frequently permitted*, in layers sloping *towards* the wall, a greater pressure of the earth will be exerted against it, and it must be made of corresponding strength.

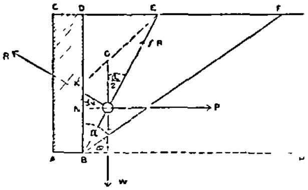
432. In dry earth cohering until disturbed, the amount of thrust may be calculated as follows:—

The slope which the earth to be supported would assume when left to itself being ascertained, the line of rupture, and the weight of the prism of earth liable to slip down that line, are thence found.

Let the accompanying figure represent an upright rectangular retaining wall, whose top is on a level with the surface of the mass retained; BF being the line of natural slope and BE the line of rupture bisecting the angle a.

BDE is the mass tending to overturn the wall, and as the weight of this mass acts vertically along the line GO; (G being its centre of gravity;) the direction of this force meets the plane BE in O.

Fig. 2.



Now, the mass BDE is kept in its place by the following forces, viz :—

R, the re-action of the plane BE, at right angles to the plane.

P, the resistance of the wall, at right angles to the back of the wall.

f R, the friction acting along the plane BE, (f being the co-efficient of friction of the earth,) and

W, the weight of the mass.

It may be shown that the point N, the centre of pressure of the earth against the wall, is one-third of the height of the wall from the base—for,

$$\text{KG} : \text{GE} :: 1 : 2, \text{ but KG} : \text{GE} :: \text{BO} : \text{OE} :: \text{BN} : \text{ND}$$

$$\therefore \text{BN} : \text{ND} :: 1 : 2, \text{ or BN} = \frac{\text{BD}}{3}.$$

The friction f R is some fraction of the pressure R, f being the co-efficient of friction. But as BF is the line of natural slope of the earth,

$f = \tan\theta = \cot a = \frac{\cos a}{\sin a}$.

Resolving these forces as follows—

$$\text{P} = \text{R}\cos\frac{a}{2} - f\,\text{R}\sin\frac{a}{2} = \text{R}\cos\frac{a}{2} - \text{R}\frac{\cos a}{\sin a}\sin\frac{a}{2},$$

$$\text{W} = \text{R}\sin\frac{a}{2} + f\,\text{R}\cos\frac{a}{2} = \text{R}\sin\frac{a}{2} + \text{R}\frac{\cos a}{\sin a}\cos\frac{a}{2}$$

$$\therefore \frac{P}{W} = \frac{\cos\frac{a}{2} - \dfrac{\cos^2\frac{a}{2} - \sin^2\frac{a}{2}}{2\cos\frac{a}{2}}}{\sin\frac{a}{2} + \dfrac{\cos^2\frac{a}{2} - \sin^2\frac{a}{2}}{2\sin\frac{a}{2}}} = \frac{\dfrac{1}{2\cos\frac{a}{2}}}{\dfrac{1}{2\sin\frac{a}{2}}} = \frac{\sin\frac{a}{2}}{\cos\frac{a}{2}} = \tan\frac{a}{2}$$

and $P = W \tan\frac{a}{2}$ or $= \frac{w}{2} h^2 \tan^2\frac{a}{2}$; w being the weight per cubic foot of the earth.*

Therefore, the moment of the earth pressure against the wall $= P \times \frac{h}{3}$ (h being the height of the wall), $= \frac{h}{3} W \tan\frac{a}{2} = \frac{w}{6} h^3 \tan^2\frac{a}{2}$, and this may be equated with the moment of stability of the wall.

It will be observed that the moment of stability of the wall, as understood here, is purely statical, and no account has been taken of the additional strength which the wall could offer through the resistance (to *direct tension*) of the mortar joint at AB.

Practically, however, this is so small as compared to the statical resistance of the weight of the wall, that it is always omitted in calculation, and masonry or brickwork structures are designed on the supposition that the joints have no appreciable tenacity.

If w_1 be the weight, per cubic foot, of the masonry of the wall, h the height, and b the base; then, if we leave the mortar joint out of the question, the moment of stability of the wall will be $\frac{w_1 h b^2}{2}$, and equating this with the moment of the earth pressure, we have—

$$\frac{w_1 h b^2}{2} = \frac{w}{6} h^3 \tan^2\frac{a}{2}$$

$$w_1 b^2 = \frac{h^2 w}{3} \tan^2\frac{a}{2}$$

$$\therefore b = \sqrt{\frac{h^2 w}{3 w_1} \tan^2\frac{a}{2}}$$

$$= 58\, h \tan\frac{a}{2} \sqrt{\frac{w}{w_1}}$$

* If the body to be supported by the wall were a perfect fluid, such as water, the value of θ would be 0, and $a = 90°$, therefore this expression would become $\frac{w}{2} h^2 \tan^2 45° = \frac{w}{2} h^2 =$ (for water) $\frac{62\frac{1}{2}}{2} h^2 = 31{\cdot}25\, h^2$; $62\frac{1}{2}$ lbs. being the weight of a cubic foot of water.

433. In this equation the line of resistance,—the line of resultant pressures,—has been assumed to pass through the outer angle of the base of the wall, and the wall would be in a position of bare stability, being in exact equilibrium with the overturning pressures: so that some margin must be allowed to the wall for stability. This stability would be decreased by any saturation of the earth retained; but increased by precautions for thorough drainage at the back, by filling in with chips and shivers of the stone used in building, by the arrangement of the earth in punned layers, by the friction of earth, &c., against the roughened or 'stepped' back of the wall, and by the tenacity of the mortar joining the wall to its foundation courses. It must also be borne in mind that for actual materials of construction, it is of course necessary that the line of resultant pressures should not be so near the nearest edge of the joint as to produce a pressure at that edge sufficiently intense to injure the material.

The following 'practical' additions may be made to the breadth as above calculated:—

$\frac{1}{10}$ b for well drained banks with horizontal surfaces.

$\frac{1}{6}$ b for well drained banks with sloping surfaces.

$\frac{1}{4}$ b for walls where the materials is considered treacherous, or for dams over rivers, where floods have considerable velocity.

434. But in lieu of giving any fractional increase to the breadth of the base of a retaining wall, Professor Rankine advocates the following principle; "the line of resistance must not deviate from the centre of figure of any joint by more than a certain fraction (q) of the diameter of the joint measured in the direction of the deviation." He adds, that an examination of practical examples determines values for the fractional deviation of the line of resistance from the centre of the base, which give $qb = \frac{3}{8}b$ to $\frac{1}{4}b$.

These principles are examplified in *Figs* 3 and 4. In the former figure (R) the resultant of the moments of the pressure (P) and of the weight of wall (V) passes through the extreme edge of the base of the wall, while in *Fig* 4 its deviation from the centre of the base c is limited to the distances CD = qb. In obtaining equations for the breadth of walls, in which the deviation is thus limited, we must equate the moments of stabilities and pressures round the extreme limit of deviation at D.

Fig. 3.

Fig. 4.

435. There is another consideration which should influence the dimensions of walls, viz —that they should not slip forward on their bases from the horizontal pressure; it is easily shown that this will not occur so long as the resultant (R) makes an angle with the horizon greater than the angle of repose, which for green masonry is considered to be $30\frac{1}{2}°$. It is seldom necessary to investigate whether this condition is fulfilled or not; for even in walls of the smallest sectional area, the resultant makes an angle of over 40° with the horizon; and the angle increases with the decreasing values of q. Further, the cohesion of the mortar is a very considerable element in this, as it is called, frictional stability of a wall, and it is neglected in the investigations connected with friction.

436. Instead of the earth being dry and hard, though not hard enough to be self-supporting, it may be supposed to be semi-fluid, that is, that all its particles may be separately set in motion: the pressure of a fluid such as water (specific gravity = s) is as $\frac{h^2 s}{2}$ applied at D with a leverage $\frac{h}{3} = \frac{h^3 s}{6}$: that of earth will be modified in various degrees by cohesion in different soils, and thus it becomes a question to be determined by experiment, and is shown by the angle assumed by the soil, when left by itself and by the height at which a section of it will for a time stand, when cut perpendicularly. Weisbach states that, according to circumstances a vertical face of from 3 to 12 feet sustains itself in various soils, but this is only temporary: whilst in fine sand or newly turned earth, no appreciable height is thus sustained.

The following are the natural slopes or angles of repose of various soils:—

Fine dry sand, - - -	35° 30′	Common earth, dry - -	46° 30′
Gravel, - - - - -	39°	Ditto, damp, - - -	54°
Loose shingle, dry, - -	39°	Ditto, the most compact, -	55°

The following table shows the base to be given to triangular retaining walls of specific gravity equal to that of the earth sustained (supposed to be twice that of water) in terms of the height; the substance supported being supposed to be level with the top of the wall.

	Nature of substance supported.	Length of base in terms of height of wall, 133 lbs. per cubic foot.
1.	Vegetable earth, carefully laid course by course, - -	·153
2.	Clay, well rammed, - - - - - - -	·193
3.	Earth, mixed with large gravel, - - - - -	·230
4.	Sand, - - - - - - - - - -	·270
5.	Sand, or mud in a fluid state, - - - - -	·700
6.	Water, - - - - - - - - - -	·500

437. Best Form of Retaining Wall.—It is evident that the pressure being greatest at the bottom of the wall, whilst at the top it is nothing, a gradual diminution of the thickness of a revetment towards the top is thereby indicated; against overturning by the action of a prism of earth at its back, this diminution would be in direct proportion to the height, and the form would be a triangle. Against the pressure of a fluid tending to thrust the wall forward by destroying the cohesion of its joints, the diminution would be as the square of the height, which would give a concave batter in the form of a parabola for the outer surface of the wall. In practice, however, this is an expensive form, from the extra labor required in forming the curve; and as for masonry intended for permanent exposure to destructive influences, the top of the wall cannot be brought to an edge, but must have a certain thickness, a frustum of a prism becomes the best practical form.

The following general rule is often adopted for practical purposes; let the width of the wall at the base be as in the table above given, according to the nature of the substance to be supported: the thickness at top about 1-10th of the height of the wall, up to 30 feet; the minimum thickness under any circumstances being $1\frac{1}{2}$ feet; the maximum 3 feet; which need never be exceeded whilst the surface supported is level with the top of the wall.

The front batter may be made to suit the circumstances of the case in regard to convenience, appearance, &c., but may generally with advantage be made equal to half the difference in thickness between the bottom and top of the wall; the front face should be smooth, the rear face set off in steps at equal distances in the back, which should be left as rough as the nature of the materials will admit of.

In a large structure, however, these empirical rules might add to its mass and expense with an actual diminution of strength: so that it will be necessary to calculate the correct form according to Delocre's or Rankine's methods, referred to in paras 448 and 449

438. Another point to be considered is, if in addition to the weight of the ground behind the revetment, this ground is loaded by earth, buildings, &c., resting on it; if this weight is not thrown back beyond the line of rupture, allowance must be made for it by calculating the dimensions of a triangular revetment as for a height of earth equivalent to that weight, and then cutting it down to the height to which the wall is to be built, so

of different composition lying on each other sometimes slip, from water penetrating between the strata; chemical changes sometimes take place from the exposure of certain soils to the air, causing motion, and often occasioning slips; some very serious ones have been attributed to this cause in the London and Croydon Railway; now retaining walls cannot be built to withstand thrusts of this nature, but they must be allowed to expend themselves, or a state of rest in the strata must be restored in some other way.

When the material at the back of the wall is of a loamy description, and liable to be reduced to quicksand or mud by saturation with water, and there are no means of preventing such saturation by efficient drainage, one way of making provision to resist the additional pressure which may arise from such saturation, is to calculate the required thickness of wall, as if the earth were a fluid, making $\theta = 0$ in the formulæ.

Another way of providing against such a contingency is to construct, sloping against the back of the wall, a bank of shivers of stone or coarse gravel, whose angle of repose is not affected by the presence of water, and then to fill in the softer material. The pressure against the wall in this case will not at any time greatly exceed that of a bank of the firm material employed, sloping at its own angle of repose.

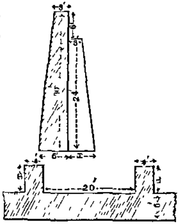
Another mode of relieving retaining walls from pressure is by the aid arches, as described in para. 415.

443. Counterforts.—Retaining walls are often built with counterforts, or buttresses, at short distances apart, which allow of the average section of the wall being made less than would otherwise be the case, by enlarging the base of the structure in a greater proportion than its mass; care must be taken thoroughly to unite the brickwork or masonry of the revetment with that of the counterforts, or the former may be forced forward leaving the counterforts behind.

Counterforts well united with a retaining wall are of the same advantage to it as cross walls in the superstructure of houses. Buttresses in front of a wall are more advantageously situated to prevent overturn than counterforts, but are of course inapplicable where a straight-faced wall is required. Counterforts too have the advantage of breaking up or dividing the pressure of the earth behind a revetment, and especially when this is caused by the filtration of water.

The size of counterforts will depend on the height of the revetment; but about one-eighth of the calculated mass of masonry or brickwork may generally with advantage be thrown into this form; the distance of the counterforts from each other may range between the limits of 20 feet for high, to 10 for low, walls; they need not reach to the top of the revetment, by double the thickness of the revetment at top, that portion being already stronger than is requisite for stability; their length at top may be equal to the top thickness of the revetment, and their breadth one-fifth of their distance apart. And from these dimensions the length of the counterfort at bottom may be found. Thin counterforts at frequent intervals will be more efficacious in breaking up the pressure to be sustained than thicker counterforts at longer intervals.

Fig. 6.



Thus in a revetment 30 feet high, 3 feet thick at top, 6 feet thick at bottom, with counterforts 20 feet apart, the length of these counterforts at bottom will be found easily, their breadth being 4 feet; for one-eighth of mass of revetment equals that of counterfort, so that making the length between the counterforts 20 feet, we have, $\frac{x+3}{2}(30-6)$ $\times 4 = \frac{1}{8}\left\{\frac{6+3}{2} \times 30 \times 24 + \frac{x+3}{2}(30-6) \times 4\right\}$, which gives $x = 6{\cdot}64$ *feet.*

444. Hollow revetments.—In cases where the mass of brickwork required is sufficient to enable it to be divided into walls of not less than 2 feet in thickness, revetments may with advantage be built hollow, that is consisting of a front and rear wall, with partition walls taking the place of counterforts at intervals: in cases where an average thickness of more than 4 feet throughout, is required, the front wall may be made thicker than the others with a batter as in ordinary revetment walls.

445. Relieving Arches are those turned on the counterforts, as piers, to carry the superincumbent filling, the counterforts, being of such

length that the earth scarcely comes into contact with the back of the wall.

The wall is thus a mere shell blocking up the faces of the archways.

The arches may be in one or more tiers, and their length should be so great that the line of natural slope of the earth, touching their intrados at the crown, should not cut the line of the back of the wall above the crown of the extrados of the next tier (*vide Fig.* 7).

Fig. 7. Section.

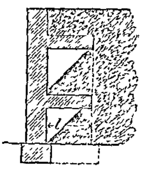
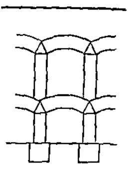


Fig. 8. Back elevation.



To compute the length, l, of a relieving arch and counterfort on which it stands; being given—the clear height, h, of the crown.

Let d = the depth of the crown of the arch below the surface.

θ = the angle of repose of the earth.

We have,* approximately—

$$l = \cot \theta \left(h + \frac{d}{(1 + \sin \theta)^2}\right)$$

and

$$h = l \tan \theta - \frac{d}{(1 + \sin \theta)^2}$$

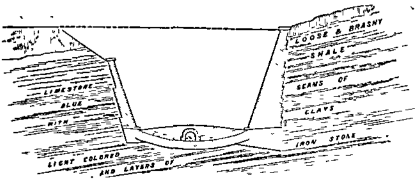
446. Breast Walls.—These are used rather to defend the surface of a cutting from the weather, and thus keep it from falling by disintegration, than to support any part of the mass behind it. Most soils will stand at a much stiffer slope, when first cut, than afterwards: in these cases a mere facing of masonry will often be sufficient, taking care to build it as soon as possible after the cutting has been made, before the surface has suffered from exposure, and not to leave the slightest interstice behind the wall; such interstices, if they exist, should be filled in with small gravel carefully rammed, or with clay puddle.

Sloping revetments of even thickness not exceeding 2 to $1\frac{1}{2}$ feet may often be used with advantage in such cases; and when the slope is very great, and approaching the permanent angle of repose, planting grass,

* Rankine's Civil Engineering.

sodding, or covering the slope with rough flat stones, will prevent disintegration of the surface.

Fig. 9.



In cutting through strata which dip considerably, it will often be requisite to have a strong revetment on one side, whilst a thin facing will be sufficient on the other, as shown in the above figure.

As the permanency of breast walls is entirely dependent on motion not taking place in the mass behind them, special care must be taken to prevent the access of water to the back of such walls.

447. Masonry Dams.—In the case of high masonry dams for retaining water, the conditions differ somewhat from those of earth retaining walls as above described. The dam is liable to be destroyed in three ways; it may be *overturned* by the thrust of the water; it may *slide* on its base or its joints: or it may *crush in* vertically from its own enormous weight.

There is no case, however, on record of any dam having been overturned, or having been destroyed from having slidden horizontally: every dam that has been destroyed hitherto, has crushed in from its own weight. It follows, therefore, that to add more material than is necessary, is not to strengthen, but to weaken the work. As mortar may be assumed to be the weakest material in the structure; the calculations must be based on the strength or weakness of the mortar, and the pressure on no horizontal layer of the dam should exceed the safe amount of compression to which the mortar may be subjected. Assuming then a practical width for the top of the dam, and proceeding downwards, immediately that layer is reached where the pressure approaches the safe amount (say 80 lbs

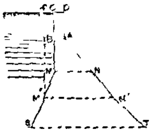
on the square inch) the width of the layer must be increased, so that no portion of the masonry shall be called upon to resist more than the allotted amount of compression. Such a dam, moreover, is subject to two different sets of conditions: viz., (1) when the reservoir is empty, and the pressures on the inner face become most intense; and (2) when it is full and from the thrust of the impounded water the pressures on the outward face are most intense.

448. *Furens' Dam.*—The French Engineer, M. Delocre, designed masonry dams 164 feet in height, on these considerations, and the forms adopted are shown in *Plate* LXII.

His process is briefly this:—He divides his wall into three parts, see *Fig.* 10.

1st.—A vertical rectangular portion CDBA of a breadth equal that selected for the top of wall; in this portion the maximum unit pressure will at all points, except the lower portion at A, be less than the limiting pressure f'.

Fig. 10.



2nd.—A vertical backed trapezoidal portion BAMN, in which the pressure at N and M shall not exceed f' when the reservoir is either full or empty.

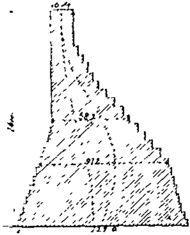
3rd.—A part MNST, which has inclinations on both face and back, and in which the limit pressure is not exceeded at the points M′ N′ or ST in a series of horizontal sections taken in the profile.

449. *Rankine's Dam.*—*Plate* LXIII illustrates the form of masonry dam recommended by Professor Rankine on the same general ideas as advocated by the French Engineers, but modified to satisfy the principle that "the lines of resistance when the reservoir is empty and full respectively, should both be within, or but a small distance beyond, the middle third of the thickness of the wall."

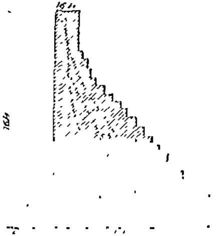
In the profile shown in the *Plate*, logarithmic curves have been adopted for both outer and inner faces. The common subtangent to both curves (marked AD in the drawing) is 80 feet.

The thickness CB at 120 feet below the top is 84 feet; and of this one-fourteenth, AC = 6 feet, lies inside the vertical axis OX, and thirteen-fourteenths, AB, 78 feet, outside that axis. The formula for the thickness t at any depth x below the top, is as follows:—

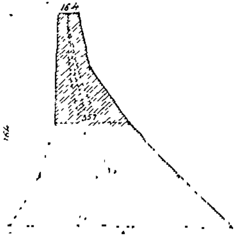
Theoretical Type (in steps) for a short Dam.



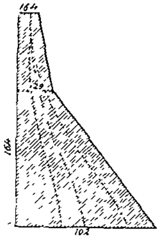
Theoretical Type (in steps) for a long Dam.
85 lbs on the Square Inch.



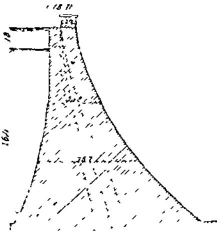
Theoretical Type (without steps)
85 lbs on the Square Inch.



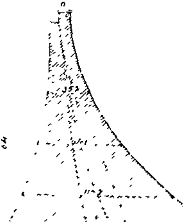
Theoretical Type (without steps)
199 lbs on the Square Inch.



Dam of Gouffre d'Enfer
Reservoir of Furens



Dam of Ban



$$t = t_1 e^{\frac{x - x_1}{a}} \quad \text{.......................................} \quad (1).$$

Or, in common logarithms,

$$\log t = \log t_1 + 0{\cdot}4343 \frac{x - x_1}{a} \quad \text{.........................} \quad (1A),$$

in which a denotes the subtangent (60 feet), and t_1 the given thickness (84 feet) at the given depth (120 feet) below the top. The thickness at the top is 18·74 feet.

The range of different depths to which the same profile is applicable without any waste of material extends from the greatest depth shown on the drawing, 180 feet, up to 110 feet, or thereabouts. For depths between 110 feet and 80 or 90 feet, or thereabouts, the waste of material is unimportant. For depths to any considerable extent less than 90 feet, the use of a part of the same profile gives a surplus of stability. For example, if the depth be 50 feet, the quantity of material is greater than that which is necessary in the ratio of 1·4 to 1, nearly. For the shallow parts, however, at the ends of a dam that is deep in the centre, it is preferable to use the same profile as in deep parts, notwithstanding this expenditure of material, in order that the full advantage of the abutment against the sides of the ravine may be obtained. In the case of a dam that is less deep in the centre than 110 feet, the following rule may be employed. Construct a profile similar to that suited to a depth of 110 feet, with all the thicknesses and ordinates diminished in the same proportion with the depth. The intensity of the vertical pressure at each point will be diminished in the same proportion also; but this does not imply waste of material; the whole weight of the material being required in order that there may be no appreciable tension in any part of the wall.

450. In order that the pressure may be equally distributed through the work, the dam should be one homogeneous mass, built in every part of the same kind of material. No. interior or exterior facing of ashlar, which may have a tendency to separate from the rest of the work, and no *partial* use of cement or concrete must be permitted. In order to increase the resistance to sliding, horizontal courses must be rigorously avoided, (the bed-joints of such courses tending also to become channels for the leakage of water). The dam must simply be a mass of uncoursed rubble laid in hydraulic mortar, without any hollows, every portion resembling the rest of the work as closely as possible.

The very fact, however, of the irregular structure of 'uncoursed rubble'

masonry render necessary unusual care and vigilance in superintending its *erection, in order to insure that every stone shall be thoroughly and* firmly imbedded, and that there shall be no empty hollows in the interior of the wall, nor spaces filled with mortar alone where stones ought to be placed. In such work the practice of "grouting" or filling hollows by pouring in liquid mortar should be strictly prohibited.

Should it be decided to insert in the face of the wall headers or long bond stones, these stones should be laid with their lengths not horizontal, but *normal to the face of the wall.*

The foundation should be sound rock if practicable; it may be doubted if *any* earthen foundation is thoroughly to be relied on where the depth of water exceeds 100 or 120 feet.

SECTION V.—STRENGTH OF MATERIALS.

Preface—It was intended that the whole of the Chapters on "Applied Mechanics," scattered in different parts of the original Treatise, should have been collected together, adapted to a uniform system and notation, and re-written, where necessary, to bring them up to the state of Modern Science, to form together a College Manual of Applied Mechanics. But the call for a new Edition of the Treatise has been for some time so urgent that this plan could not be carried out in this edition: such Chapters only as were ready for the new Manual have been inserted: the following Chapters have been entirely re-written* on a uniform plan.

- XXI. Preliminary.
- XXII. Tension.
- XXIII. Compression.
- XXIV. Elasticity.
- XXV. Stresses in Trusses.

This explanation is necessary to explain the evident difference of scope of these from the remaining Chapters, and the at present unavoidable absence of many references to articles not printed with this edition.

This will be remedied in the next edition

The following is a list of the authorities which have been consulted in preparation of the new Chapters. All results given have been in every case compared with the originals here quoted:—

Bélidor, ...	... La Science des Ingénieurs, ...	1813
Barlow, P.,	Essay on Strength and Stress of Timber,	1826
	Strength of Timber, &c., ...	1845
	Strength of Materials, ...	1867
Whewell, W.,	... Mechanics of Engineering, ...	1841
Rondelet, ...	... L'Art de Bâtir, ...	1842
Tredgold, T.,	... Strength of Cast-iron, &c., ...	1842
Morin, A., ...	... Résistance des Matériaux.	
Hodgkinson, E.,	Experimental Researches on the Strength, &c., of Cast-iron, ...	1846
Moseley, H.,	... Mechanical Principles of Engineering and Architecture,...	1843

* By Capt. Allan Cunningham, R.E., Hony Fellow of King's College, London.

Rankine, W. J. M., ...	Manual of Applied Mechanics, ...	1864
	Manual of Civil Engineering, ...	1870
	Useful Rules and Tables, ...	1870
Fairbairn, W., ...	Application of Cast and Wrought-iron to Building purposes, ...	1864
	Useful Information for Engineers, ...	1864
Medley, J. G., Major, R.E., ... Lang, A. M., Major, R.E., ...	Professional Papers on Indian Engineering. First and Second Series, ..	1864 to 1872
Thomson, Sir W., ... Tait, P. G., ...	Natural Philosophy, ...	1868
Medley, J. G., Major, R.E.,	Roorkee Treatise on Civil Engineering *in India*, ...	1869
Stoney, B., ...	Theory of Strains, ...	1869
Unwin, W. C., ...	Wrought-iron Bridges and Roofs, ...	1869
	On the Construction of Wrought-iron Bridges, (Chatham Lectures,) ...	1871

CHAPTER XXI.

PRELIMINARY.

Careful attention should be paid to the following definitions:—

451. Load.—The external forces applied to any Structure in Engineering are styled "Loads;" among these may be classed the weight of the Structure itself, and *also* the Re-actions of the Supports.

The combination of *all* the external forces applied to a whole Structure, or to any single piece of a Structure is called the "Load" on the Structure or on the Piece respectively: this *includes* the weight of the Structure or Piece, and the Re-actions at the supports.

Dead Load and *Live Load.*—The steady part of the Load is called "Dead Load" (this evidently includes the weight of the Structure itself): the rapidly moving part of the Load (*e. g.*, the weight of a train in rapid motion), or a suddenly applied Load (such as a shock or impact) is called the "Live Load."

This distinction is important *in practice*, as it will be shown in Art. 476, that the straining effect of a Live Load is more violent than that of a Dead Load, so that the Dead and Live Load have usually to be *separately* considered in Design.

452. Strain.—The first *observed* effect of the Load applied to a Structure or Piece is the production of some *change* in the original *Size* or *Shape* of the parts of the Structure or of the Piece, *e. g.*, elongation, contraction, distortion, &c.

This *change of size* or *shape* of whatever kind is termed "Strain": hence Strain is evidently a quantity that can be seen and measured. Load applied in different ways produces different kinds of change of size and shape, *i. e.*, Strain of different kinds.

The whole Strains produced by a given Load are not produced quite suddenly, but *time* is required to allow the whole straining effect to take place.

N.B.—Many authors use the term "Strain" both in the sense used here, (and which alone will be used in this Manual,) and *also* to signify what is termed "Stress" in this Manual. The distinction here drawn between the two is adopted now in many Scientific Works, and will be found very convenient.

453. Resistance and Strength.—The support offered by any Structure or Piece to the Load applied is termed "Resistance." The *power* of resisting the fracture which Load tends to produce is termed "Strength." The "Strength" of a Piece is *measured by* the "Resistance" it offers to the "Load."

Thus Strength and Resistance are not synonymous: Strength is merely a *quality* of materials which is measured *quantitatively* by Resistance.

Before the straining action of a Load is complete, there is motion, (viz., change of Strain) among the particles of the material, so that the Total Load is evidently greater than the Total Resistance called into play at that instant. The determination of the "Resistance" at any instant *before* the straining action is complete is a *very complex* problem in Dynamics, but this determination is never required in ordinary Engineering.

When the straining action of the Load is *complete*, there is no further motion, so that there is *then* equilibrium between the Load and Resistance.

In ordinary Engineering this case only is considered, and thus

Measure of Strength = Resistance = Load..............(1).

454. Stress.—This term is applied to the combination of forces *on either side* of any arbitrary section through a structure or piece.

Thus it partakes of the nature of both *Load* and *Resistance*, and may be divided into *External Stress* and *Internal Stress*. *External Stress* on

any Piece of a Structure may be defined as the Resultant of the Loads applied *directly* to other Pieces of the Structure and transmitted through them to the Piece in question. Thus *External Stress on any Piece is the* "Virtual" Load on that Piece due to load indirectly applied.

Example.—The resolved parts of the Loads parallel to the bars of a Framed Structure are called the *Stresses on* or *along those Bars*. These are *External Stresses.*

Internal Stress at any section is the combination of forces *at either side* of any section, those on one side being due to the action of the Load transferred through the material of the piece to that section, those on the other side being due to the Resistances of the material at the Section. Hence referring to equation (1) since there is equilibrium when the *straining action is complete.*

Load or External Stress = Resistance (or Strength) = Stress....(1A.)

455. Load, Strain, Resistance, Strength, and Stress.—It will be observed that *Load* produces as its first effect *Strain*, which is opposed by *Resistance*, and that the combination of forces produced by the Load on either side of any section is termed *Stress* (viz., Internal Stress): thus Strain, Resistance, and Stress are all *produced* by the Load.

Also *Load*, *Resistance*, and *Stress* are *of the same kind*, and measurable in the same units (generally in pounds or tons). *Strength* is merely a quality, *measured* by Resistance, but nevertheless inherent in material.

Strain is a visible quantity, measurable in inches, in circular measure, &c.

The following is an illustration of the meaning of these terms:—

Example.—A man lifts a weight W. Then W is the LOAD: the *elongation* in any sinew of his arm *produced by the Load* is the STRAIN of that Sinew: *the support given to the Load at any section of the sinew is the* RESISTANCE at that section: *either* of the set of forces on either side of the section is the STRESS at that section; when motion, *i. e.*, change of strain, has ceased, these Stresses are equal and opposite: the sinew is *in a state of strain*, viz., elongation: the feeling of exertion or fatigue is an evidence and a *measure* of the Stress.

456. Intensity Classification.—The five quantities, LOAD, STRAIN, RESISTANCE, STRENGTH, and STRESS are *simultaneously* classified into four Classes, according to their intensities, viz. (1), Breaking or Ultimate; (2), Proof; (3), Working or Safe; (4), Actual.

As all five vary *simultaneously*, they all five receive these qualifying attributes simultaneously: their mutual relations are as already defined and Equation (1A) is applicable.

(1). The *Breaking Weight* or *Load* is that "Dead Load" which is just sufficient to produce *fracture*. It will be denoted by P (measured in lbs.). It produces the *Ultimate Strain, Ultimate Resistance* and *Ultimate Stress.*

The *Ultimate Strength* is measured by the *Breaking Weight.*

(2). The *Proof Load* is that "Dead Load" which will *prove* or test a Piece (by straining it) *to the utmost extent possible without permanent injury.* It produces the *Proof Strain, Proof Resistance* and *Proof Stress;* the *Proof Strength* is measured by the *Proof Load.*

It has been ascertained (by experiment) to be a certain fraction (depending on the material) of the Breaking Weight, varying from $\frac{1}{2}$ to $\frac{1}{3}$.

(3). The *Working* or *Safe Load* is the *maximum* "Dead" Load which a Piece *can bear safely for a length of time.* It will be denoted by W (measured in pounds). It must obviously be less than the Proof Load to provide against defects in material or workmanship. It is usually taken as some fraction (ascertained by experience) of the *Breaking Weight* or of the *Proof Load.* It produces the *Working* or *Safe Strain*, the *Working* or *Safe Resistance*, and the *Working* or *Safe Stress.*

The *Working* or *Safe Strength* is measured by the *Working* or *Safe Load.*

The *Working* or *Safe* LOAD, STRAIN, RESISTANCE, STRENGTH, and STRESS are by far the most important in Engineering of the four classes in this Classification. It is *an invariable rule in Engineering* that all Structures must be *designed* to carry this Load (being the maximum intended load) *safely as a permanency.*

(4). The *Actual Load* is *any* Load that may be actually on a Structure or Piece. It should of course be, if temporary, less than the *Proof Load*, and if of any duration less than the *Working* or *Safe Load* (being that for which the Structure was designed). It is sometimes but not often necessary in ordinary Engineering to consider the effects of this Load, viz., *Actual Strain, Actual Resistance, Actual Stress.*

457. Factor of Safety.—This has been variously applied by different writers to each of the three following ratios, viz.:—

Breaking Weight : Proof Load : Working or Safe Load.

In this Treatise it will generally be applied to the ratio of Breaking Weight to Working or Safe Load, and denoted by s.

Hence Factor of safety = Breaking Weight ÷ Working Load,

$$i.\,e.,\ s = \mathrm{P} \div \mathrm{W},\ \text{and}\ \mathrm{P} = s\,\mathrm{W}, \quad \ldots\ldots\ldots\ldots(2).$$

In consequence of Live Load, *i. e.*, Load suddenly applied, producing *at first* in general twice the effect (*see* Arts. 476 and 477 on Resilience) of Dead Load, *i. e.*, Load gradually applied, it is usual to make the Factor of Safety for Live Load of all kinds, (*e. g.*, rapidly moving Loads) twice that for Dead Loads, the "Breaking Weight" being *by definition* determined by experiment on Dead Loads.

Hence if W' be the *Dead Load*, W'' the *Live Load* on a Structure, also s', s'' the *Factors of Safety* applicable, then

$$\mathrm{P} = s'\,\mathrm{W}' + s''\,\mathrm{W}'' \text{ or } \mathrm{P} = s'\,\mathrm{W}' + 2\,s'\,\mathrm{W}'' \quad \ldots\ldots\ldots(3).$$

Factors of safety are fixed by experience, they vary for different materials, and for different applications of Load: the values given by different authorities also vary.

The *Proof Load* of Cast-Iron and Wrought-Iron is generally given as $\frac{1}{3}$ of Breaking Load.

Timber, Stone, and Brick are not generally exposed to proof, so that no well established ratio exists for them.

The following values of Factors of Safety are given on authority of Prof. W. J. M. Rankine* as a *general* summary of experience of the profession.

Conditions.	Value of $s = \mathrm{P} \div \mathrm{W}$.	
	Dead load.	Live load.
For perfect materials and workmanship, ...	2	4
For good materials and workmanship :—In metals, ..	3	6
„ „ „ „ timber, ..	4 to 5	8 to 10
„ „ „ „ masonry, ..	4	8

Other values will be given in detail in the appropriate places: it may here be noted that many authors consider the proper value of s for timber to be 10 *for Dead Load*.

458. Modulus of Fracture or Rupture.—The *intensity of Break-*

* Rankine's Civil Engineering, 6th Edition, Art. 143.

ing Weight in pounds per square inch of area is called the Measure or MODULUS OF RUPTURE: it will be denoted by f with a letter subscript to indicate the kind of fracture intended, (*see* Art. 461). Thus—

Modulus of Rupture or $f =$

$=$ Intensity of Breaking Weight (in pounds per square inch) $=$

$=$ Breaking Load of a Piece of one square inch area of cross section .... (1).

459. Applications of Load.—There are two *principal modes of application of Load*, viz., I. LONGITUDINAL, II. TRANSVERSE.

I. *Longitudinal* or *Direct Load* is direct in its application; it is subdivided into two principal opposite varieties, viz., (1), *Tensile*; (2), *Compressive.*

II. *Transverse Load* is indirect in its application; it is subdivided into (1), Shearing; (2), Twisting; (3), Bending. Each of these five *modes of application* of Load produces its peculiar kind of *Fracture, Strain, Resistance* and *Stress*, some of which have distinctive names. The form of Strength and the Modulus of Rupture peculiar to each kind of Load-application receive a similar name. These are exhibited in one view in the following Table, to which the additional terms, viz., State of Strain and Pliability (*see* Art. 536) have been added.

Load applied in one manner will, however, frequently produce Strain and Stress, &c., *of several kinds* at once besides that enumerated as peculiar to it. This will appear in the sequel.

The *most important of these applications of Load* to Engineering Structures are—(1), TENSILE; (2), COMPRESSIVE; and (3), BENDING. It will be shown that *Bending* may be resolved into—(1), *Tensile*; (2), *Compressive*; (3), *Shearing*, Stresses. Structures in Engineering are *seldom exposed to twisting*, so that the Twisting application of Load seldom requires to be considered.

It follows that the kinds of Strain and Stress of primary importance are —(1), *Tensile*; (2), *Compressive*; (3), *Shearing*—and of these the first two are by far the most important in Engineering.

460. It may seem that an unnecessary number of terms have been introduced into the above enumeration. It is in fact not necessary to make use of them all in one book: nevertheless they are *all* in common use in the profession, and require to be understood in order that Works of different authors may be read intelligently.

Load.	Mode of Application.	Strain.	State of Strain.	Strength.	Stress.	Fracture.	Pliability.	Subscript Letter used in Notation.	Modulus of Rupture.	Modulus of Elasticity.
I. Direct, Longitudinal.	Pulling. Stretching.	Extension. Elongation. Lengthening.	Tension.	Tenacity.	Tensile.	Tearing	Extensibility.	t	f_t	E_t
	By Pressure. By Thrust.	Compression. Contraction. Shortening.	Compression.	Crushing Strength.	Compressive. Crushing.	Crushing.	Compressibility.	c	f_c	E_c
II. Transverse.	Tangential.	Distortion. Disfigurement.	Shear. Sliding.	Shearing Strength.	Sliding. Shearing.	Shearing.	Distortibility.	s	f_s	E_s
	Rotatory. Twisting.	Rotation. Torsion.	Torsion.	Twisting Strength.	Twisting.	Wrenching.	..	w	f_w	..
	Transverse. Bending.	Deflexion.	Flexure. Bending.	Transverse Strength.	*Compound of* Tensile, Compressive, Shearing.	Cross-breaking. Rupture.	Flexibility.	b	f_b p_b	E_d

s'' = Factor of Safety (applicable to Live Load W″) = $P \div W''$,

s_t = Safe intensity of direct Tensile Stress (in tons per square inch) $= f_t \div 2240\, s$.

s_c = Safe intensity of direct Compressive Stress (in tons per square inch) $= f_c \div 2240\, s$.

A = Area (in square inches) of a cross section of any material.

A_t = Net area (in square inches) of tension flange.

A_s = Area (in square inches) of web.

A_c = Gross area (in square inches) of compression flange,

$$\therefore A = A_t + A_s + A_c \text{ (in Girders).}$$

b = breadth (in inches) of the area A.

d = depth (in inches) of the area A.

t = thickness (in inches).

$$\left.\begin{array}{l} l = \text{length (in inches)} \\ L = \text{length (in feet)} \end{array}\right\} \therefore l = 12\, L.$$

λ = Strain (in inches) of l.

λ_t = Elongation (in inches) of l.

λ_c = Contraction (in inches) of l.

E = Modulus of Elasticity in pounds per square inch.

E_t = Modulus of Tensile elasticity in do.

E_c = Modulus of Compressive elasticity in do.

E_d = Co-efficient of Deflection-elasticity in do.

δ = Maximum deflection in inches.

x, y, z = Co-ordinates of length, breadth and depth (in general).

462. Principles of Design.—"Design" is the art of arranging material to the best advantage to carry given Loads. In theoretical Applied Mechanics this is to be understood to mean in the manner most favorable to utilizing the full powers of Resistance of the material, and therefore most favorable to *economy of material*, (after giving due regard to other considerations, such as æsthetic, convenient, pecuniary, &c).

The Principles of Design may be thus summed up:—" *After the straining* " action of the Load on a Structure is complete, there is *statical equilibrium* " amongst all the forces *at each point* of the Structure, so that the principles " of equilibrium of *rigid* bodies (as given in Elementary Statics) are *then* " applicable, both to the *whole* structure, and to *every part* of it. Fur- " ther, a structure must possess *Stability*, *Strength*, and *Stiffness* both as a " *whole*, and in *every part*."

The following relations must therefore obtain among the Loads and Resistances (*see* Arts. 463, 464, 465).

463. Stability.—The conditions are—

(1). The algebraic sums of *all* the external forces (including Weight of the structure, and Re-actions at supports) resolved parallel to *any* three straight lines at right angles (or otherwise) must separately vanish.. (5)

(2). The algebraic sum of the moments of *all* the external forces round *any* three axes at right angles (or otherwise) must separately vanish... (6).

These six conditions are *necessary* and *sufficient* for the *Stability* of the *Structure as a whole.*

The same six conditions applied separately to *each piece* of the Structure are *necessary* and *sufficient* to the *Stability* of the several pieces.

The above may be called the Conditions of Stability.

464. Strength. The conditions of sufficient Strength are quite similar.

(1). The algebraic sum of *all* the forces (whether external Loads or internal Stresses) at *every* section through the Structure resolved parallel to *any* three directions at right angles (or otherwise) must separately vanish.. (5A).

(2). The algebraic sum of the moments of *all* the forces (whether external Loads or internal Stresses) at *every* section through the Structure about *any* three axes at right angles (or otherwise) must separately vanish.. (6A).

These six conditions are *necessary* and *sufficient* to the Strength of the Structure *as a whole* at every section right through it.

The same six conditions applied *separately* at *every* section through *each* piece of the Structure are *necessary* and *sufficient* to the Strength of each piece.

465. Stiffness.—Beside Stability and Strength, a Structure must possess sufficient *stiffness*, both as a *whole*, and in *every part*, to prevent such strains as would unduly *disfigure* it, as such disfigurement alone might render it useless for the purpose intended, *although* both stable enough, and strong enough for the purpose.

The amount of disfigurement (Strain) permissible in a Structure depends chiefly on various *practical* considerations according to the *use* for which the structure is intended.

The mathematical treatment of stiffness will be considered hereafter.

466. The principles just given (Arts. 463, 464, 465,) should be carefully considered, as it will be found that the *Mathematical Treatment of Engineering* consists simply of *their repeated application*.

It might be thought that their *repeated* application as indicated would involve enormous labor. In practical Engineering, however, it fortunately generally happens, the forces are so distributed as to lie nearly all in one plane, and that the actual calculation of those out of the principal planes is unnecessary, (*e g.*, in Trusses, Girders and Arches it is seldom necessary to calculate any Stresses except those in planes parallel to the faces of the truss, girder or arch).

This materially simplifies the calculations, as though the whole set of six conditions is of course necessary to equilibrium, three only will have to be used *in general* in calculation.

These three conditions are those of equilibrium of Forces in a plane, viz.—

(1). The algebraic sums of *all* the forces resolved parallel to *any* two directions at right angles (or otherwise) in their plane must be separately zero..(5B).

(2). The algebraic sum of the moments of *all* the forces about *any* point in their plane must be zero..(6B).

This set of three conditions must of course hold both for the Structure as a whole, and for *every* piece of it, and further must hold separately among the external forces or Loads for Stability, and among the External Loads and Internal Stresses for Strength.

It is, moreover, fortunately generally possible by suitably choosing the points at which these conditions are to be applied to reduce *the number of applications* of these conditions to *about one or two for each piece* of a structure, so that the amount of *calculation* practically required is by no means so great as might appear from the mere statement of the conditions.

This will be better understood after reading the Chapters on Transverse Strain.

It should nevertheless be distinctly understood that the whole set of conditions must obtain at *every* section of *every* piece of a Structure.

467. Stress and Strain.—The treatment of combination of Stresses and of Strains in a *general* manner is far too difficult for a Work of this kind. The Student is referred to High-Class Works for their syste-

matic treatment, *e. g.*, Thomson and Tait's Natural Philosophy, and Rankine's Manual of Applied Mechanics.

In *practical* Engineering, such *general* treatment is seldom necessary. What follows will be sufficient for most cases.

468. Total or Whole, and Intensity.—Careful attention should be paid to *the distinction* between these terms as applied to *Load, Resistance, Stress* and *Strain.*

Def.—*Total* or *Whole* Load, Resistance, or Stress on a piece of material, is the sum of all the Loads, Resistances or Stresses of a given kind on that piece.

Def.—*Total or Whole* Strain is the whole visible change of size or shape.

Def.—*Uniform Intensity* of Load, Resistance or Stress *at a point* in a section, is measured by the number of *units of weight per unit of area* round *that point.*

In this Manual it is denoted by f, p, or w, with letters subscript (Arts. 459 and 461) to indicate the *character* of Stress, and is usually measured in pounds (or tons) per square inch.

Def.—*Uniform Intensity* of Strain *at a point* in a section is measured by the quantity of Strain per unstrained unit, *e g.*,

Linear Strain-intensity is measured by the Strain or Change (in inches) per linear unit, (viz., per inch,) *i. e*, is denoted by $\lambda \div l$.

Cubic Strain-intensity is measured by the change of volume (in cubic inches) per cubic unit (viz., per cubic inch).

Shearing Strain-intensity is measured by the co-tangent of the angle of a distorted prism, square when unstrained: it will be denoted by ν.

Def.—*Variable Intensity* of Load, Resistance or Stress, also Strain *at a point* in a section are measured (by the principles of Infinitesimals) by the number of *units of weight per unit of area*, or by the quantity of *strain per unstrained unit*, respectively, round that point estimated *as if of the same uniform intensity as the actual intensity at that point.*

These definitions will be noticed to be analagous to those of the measures of uniform and variable velocities and accelerations in *elementary* Dynamics and of fluid pressures in *elementary* Hydrostatics, so should present no difficulty to the Student who has mastered those branches They will be recognized by the Student of Differential Calculus as equivalent to the following equations (compare Eq 4),

$$f = \frac{dP}{dA}, \; w = \frac{dW}{dA}, p = \frac{dP}{dA} \quad \text{.........................} \quad (7).$$

From the preceding definitions it follows that, if *intensities* of Load, Resistance, or Stress be represented by *lines*, then *Total* Loads, Resis-

The mathematical treatment of stiffness will be considered hereafter.

466. The principles just given (Arts. 463, 464, 465,) should be carefully considered, as it will be found that the *Mathematical Treatment of Engineering* consists simply of *their repeated application.*

It might be thought that their *repeated* application as indicated would involve enormous labor. In practical Engineering, however, it fortunately generally happens, the forces are so distributed as to lie nearly all in one plane, and that the actual calculation of those out of the principal planes is unnecessary, (*e. g.*, in Trusses, Girders and Arches it is seldom necessary to calculate any Stresses except those in planes parallel to the faces of the truss, girder or arch).

This materially simplifies the calculations, as though the whole set of six conditions is of course necessary to equilibrium, three only will have to be used *in general* in calculation.

These three conditions are those of equilibrium of Forces in a plane, viz.—

(1). The algebraic sums of *all* the forces resolved parallel to *any* two directions at right angles (or otherwise) in their plane must be separately zero..........(5B).

(2). The algebraic sum of the moments of *all* the forces about *any* point in their plane must be zero..........(6B).

This set of three conditions must of course hold both for the Structure as a whole, and for *every* piece of it, and further must hold separately among the external forces or Loads for Stability, and among the External Loads and Internal Stresses for Strength.

It is, moreover, fortunately generally possible by suitably choosing the points at which these conditions are to be applied to reduce *the number of applications* of these conditions to *about one or two for each piece* of a structure, so that the amount of *calculation* practically required is by no means so great as might appear from the mere statement of the conditions.

This will be better understood after reading the Chapters on Transverse Strain.

It should nevertheless be distinctly understood that the whole set of conditions must obtain at *every* section of *every* piece of a Structure.

467. Stress and Strain.—The treatment of combination of Stresses and of Strains in a *general* manner is far too difficult for a Work of this kind. The Student is referred to High-Class Works for their syste-

matic treatment, *e. g.*, Thomson and Tait's Natural Philosophy, and Rankine's Manual of Applied Mechanics.

In *practical* Engineering, such *general* treatment is seldom necessary. What follows will be sufficient for most cases.

468. Total or Whole, and Intensity.—Careful attention should be paid to *the distinction* between these terms as applied to *Load, Resistance, Stress* and *Strain.*

DEF.—*Total* or *Whole* Load, Resistance, or Stress on a piece of material, is the sum of all the Loads, Resistances or Stresses of a given kind on that piece.

DEF.—*Total or Whole* Strain is the whole visible change of size or shape.

DEF.—*Uniform Intensity* of Load, Resistance or Stress *at a point* in a section, is measured by the number of *units of weight per unit of area* round *that point.*

In this Manual it is denoted by f, p, or w, with letters subscript (Arts. 459 and 461) to indicate the *character* of Stress, and is usually measured in pounds (or tons) per square inch.

DEF.—*Uniform Intensity* of Strain *at a point* in a section is measured by the quantity of Strain per unstrained unit, *e. g.*,

Linear Strain-intensity is measured by the Strain or Change (in inches) per linear unit, (viz., per inch,) *i. e.*, is denoted by $\lambda \div l$.

Cubic Strain-intensity is measured by the change of volume (in cubic inches) per cubic unit (viz., per cubic inch).

Shearing Strain-intensity is measured by the co-tangent of the angle of a distorted prism, square when unstrained: it will be denoted by ν.

DEF.—*Variable Intensity* of Load, Resistance or Stress, also Strain *at a point* in a section are measured (by the principles of Infinitesimals) by the number of *units of weight per unit of area*, or by the quantity of *strain per unstrained unit*, respectively, round that point estimated *as if of the same uniform intensity as the actual intensity at that point.*

These definitions will be noticed to be analagous to those of the measures of uniform and variable velocities and accelerations in *elementary* Dynamics and of fluid pressures in *elementary* Hydrostatics, so should present no difficulty to the Student who has mastered those branches. They will be recognized by the Student of Differential Calculus as equivalent to the following equations (compare Eq. 4),

$$f = \frac{dP}{dA},\ w = \frac{dW}{dA},\ p = \frac{dP}{dA} \text{ .... } (7).$$

From the preceding definitions it follows that, if *intensities* of Load, Resistance, or Stress be represented by *lines*, then *Total Loads, Resis-*

tances, or Stresses are conveniently represented by *volumes* of solids. This graphic method has the advantage of conveying clear ideas (even to those not acquainted with Integral Calculus) of both the magnitude and position of the Resultant Load, Resistance or Stress.

469. Parallel Stresses on a plane area.—Thus for a Load, Resistance or Stress (whose components are *parallel*) in the case of a *plane area* A, (*see Fig.* 1).

Let P = Total Load, Resistance or Stress distributed in *any* manner over the area A.

Let p = Intensity of the same, at *any* point P in that area whose coordinates (referred to rectangular axes Ox, Oy in the plane of A) are OL = x, OM = y.

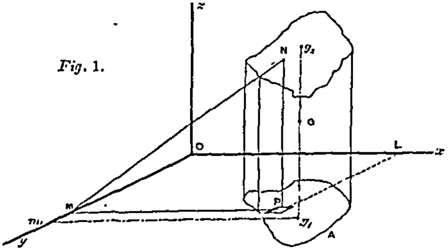
Then if the intensities (p) be represented by lines as PN drawn perpendicular to each point as P of the area A, the Total Load, Resistance, or Stress (P) will be represented by the volume of the prismatic or cylindric solid whose base is the area A, and whose upper surface is formed by the upper ends of the ordinates such as PN (which represent the intensities from point to point of the area A).

Thus if V be the volume of the solid, w the weight of a cubic unit of it, so that $p = wz$. Then

$$P = w\,V \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8).$$

Also the "Centre of Stress" is the point g_1 in the area A immediately below the "centre of gravity" G of the representative solid V ....(9).

Fig. 1.



These *two* results, which give the magnitude and position of the *Resultant* of Parallel Loads, Resistances, or Stresses *on a plane area* are perfectly

general. They cannot, however, *in general* be expressed in algebraic formulæ without the aid of the Integral Calculus.

470. Case I.—Load, Resistance, or Stress *of uniform intensity* (p). This is *the only very simple case*, and fortunately *the most useful* in Engineering. The ordinates as PN representing the intensities will evidently be of equal length, and the upper surface of the representative solid will be a plane area, equal *in all respects* to and parallel to A, so that $V = z \,.\, A$, where $z = p \div w$, a constant quantity.

Hence $P = w\,V = p \,.\, A$, also $p = P \div A$..........................(8A).

Also the "Centre of Stress" is the centre of gravity of A.........(9A).

In this case, the only difficulty in finding either P or p, when *one* is given, will be in calculating the area A. But in Engineering *practice*, the area A is usually some *simple* figure whose area can be immediately found by Elementary Geometry.

N.B.—Of course result (8A) could be obtained at once by integration from Eq (7) thus $dP = pdA$, $\therefore P = \int pdA = p\int dA = pA$.

Case II(a).—Load, Resistance or Stress *of variable intensity* (p), but *of the same sign*, *i. e.*, entirely tensile, entirely crushing, or entirely shearing of one direction. In consequence of the ordinates as PN (representing the intensities) varying from point to point of the area A, the representative volume V cannot be expressed algebraically without the aid of the Integral Calculus.

Here $P = wV = w\iint z\,dx\,dy = \iint p\,dx\,dy$ ....(8B).

the integral being extended over the whole area A.

Result (9) cannot be more simply expressed · if $\bar{x}, \bar{y}$ be the distances of g, the "centre of Stress" from the axes, then it is shown in Works on Analytical Mechanics that

$\bar{x} = \left\{\iint px\,dx\,dy\right\} \div P$, $\bar{y} = \left\{\iint py\,dx\,dy\right\} \div P$........(9B).

the integral being extended over the whole area A.

Also if p_o = mean intensity of P, (*i. e*, as if uniformly distributed), Then—

$P = p_o . A$, and $p_o = P \div A$ ....(10B).

Case II(b).—Load, Resistance, or Stress *of variable intensity* (p), but of two contrary signs.

This should be treated as Case II(a) by the method of Case III(b), following.

Neither Case II(a) nor II(b) are of much importance in Engineering.

Case III.—Load, Resistance, or Stress *of uniformly-varying* intensity. This is the most simple case of varying Stress, and fortunately *one of the most useful* in Engineering.

By "uniformly-varying" is meant varying as the distance from some fixed line in the area A: this line may be called the "line of no Stress."

In this case also the Results (8), (9) cannot be expressed algebraically in *a general form*, (*i. e.*, applicable to any figure) without the aid of the Integral Calculus.

But in Engineering *practice*, the areas are *of such simple figure*, and the "line of no stress" *so situate with respect to them* that the Results (8) and (9) can generally be evaluated in an algebraic formula by Elementary Geometry *in each particular case*. Many examples of this will occur in the sequel, in which the Student will find that the use of Integral Calculus is not essential in the simple cases which occur in practical Engineering, although of considerable help in shortening the work.

This case may be divided into two, *both of great importance in practical Engineering*.

(*a*). Stress of one sign, *e. g.*, entirely tensile, entirely crushing, or entirely shearing in one direction.

Example.—Fluid Pressure, Earth Pressure, also Punching, Slotting.

(*b*). Stress of contrary signs, *e. g.*, tensile over part, and crushing over part of the area, or shearing of opposite directions over different parts of the area.

Example.—In Cantilevers, Beams or Girders.

Case III(*a*).—*Uniformly-varying stress of one sign.* Take the axis Oy as the line of no stress, then the condition that the stress is uniformly-varying is thus expressed, p or $PX \propto MP$ (*Fig.* 1).

i. e, $p = \varpi\ x$, (where ϖ = stress-intensity at unit-distance) ......(11).

The upper surface of the representative solid is evidently an *inclined plane* passing through the "line of no stress" Oy.

Hence result (8) may be expressed in a form similar to that given for Total Fluid Pressure in Elementary Hydrostatics, thus: Gg_t is the "mean line" of the representative solid, and therefore the line of action of the Resultant or Total Stress (P); also if g_1' be the centre of gravity of the area A, then will its projection g_2' be the centre of gravity of the upper plane surface (this being a projection of the area A): hence as in Elementary Hydrostatics; if p_o be the mean pressure,

$$w \times g_1'g_2' = p_0 = \varpi \times m_1'g_1', \text{..................(10C).}$$

$$\text{Hence } P = wV = w \times A \times g_1'g_2' = p_0 A = \varpi \times A \times m_1'g_1', \text{ (8C).}$$

N.B.—The following alterations should be made in *Fig.* 1, page 452.

Convert m_1, g_1, g_2 into m_1', g_1', g_2'.

Result (9) cannot be more simply expressed.

These results cannot, however, be expressed in an *algebraic general form*, (*i. e.*, applicable to any case) without the aid of the Integral Calculus. The *general* expressions are

$$P = \int py\,dx = \varpi \int xy\,dx, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8C).$$

$$\bar{x} = \left\{ \varpi \int x^2 y\,dx \right\} \div P, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9C).$$

$$P = p_0\ A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10C).$$

In practical Engineering, however, the figures of area A are usually so simple, and the "line of no stress," Oy so situate that the results (8C), (9C), (10C) can *often* be evaluated by Elementary Geometry *in each particular case* (although these results cannot be expressed in a *general* form except as shown). Many instances of this will occur in the sequel.

Case III(b.)—*Uniformly-varying stress of two contrary signs.* The Total or Resultant of Load, Resistance or Stress, and also the "Centre of Stress" are to be found for the Stress of each sign *separately* as in Case III(a). These two resultants form a system of two *parallel opposite* forces applied at their "Centres of Stress." Their Resultant, and its point of application (or "Centre of Stress") are to be found by the rules for a pair of parallel forces (for which see any elementary work on Statics).

If the two partial resultants be equal, there is no single Resultant, and no single "centre of Stress." The pair of *equal unlike parallel* Stresses form a "Couple" whose arm is the distance between the centres of Stress. This is the case which obtains in Cantilevers, Beams, and Girders, and will be constantly referred to in the Chapter on Bending.

471. Work.—The technical term "Work" is defined in Elementary Dynamics* as the "production of *motion* against *resistance*" and as measured by *the number of units of weight raised one linear unit in height.* The work-unit is therefore a compound unit comprehending both weight and length-units. The usual work-units are

The British work-unit of one *foot-pound*, (*i. e.*, one pound raised one foot high).

The French Work-unit of one *kilogrammétre*, (*i. e.*, one kilogramme raised one métre high).

* Todhunter's "Mechanics for Beginners," Chapter XVII., 2nd Ed.

Other Work-units are occasionally used in different problems, *e. g.*, in problems relating to Structures, it is often convenient to take the inch as the length-unit (as will generally be done in this Manual), in which case the Work-unit would be one *inch-pound*, *i. e.*, one pound raised one inch high).

472. Accumulated Work, Actual Energy, Kinetic Energy.—It is shown in works on Elementary Dynamics* that the amount of "Work" accumulated in a moving body of Weight W, or Mass M and velocity v is

$$\frac{Mv^2}{2} \text{ or } W \cdot \frac{v^2}{2g} = \text{Weight} \times \text{height due to the velocity,} \ldots\ldots\ldots(11).$$

This is also styled the *Actual Energy, or Kinetic Energy* (*i. e.*, Energy of Motion) of the moving mass.

473. Potential Energy.—The amount of Work which a body is *capable* of performing in consequence of its position, and which it would perform if free to move, and is prevented from performing solely by restraint on its motion is called "Potential Energy."

Example (1).—A weight W *supported* at a height h feet possesses *Potential Energy* measured by Wh foot-pounds, *i. e.*, if released it would fall, and accumulate Wh foot-pounds of Work in itself which would then be its *Kinetic Energy* (or Energy of Motion) or *Accumulated Work* which it would expend on the earth when brought to rest.

Example (2).—A spring or a beam bent and *retained* bent by an External weight W through a distance δ (in inches) possesses Wδ inch-pounds of *Potential Energy*, which on the removal of the weight becomes *Actual Energy* or *Kinetic Energy*, which is expended in restoring the spring or beam, (*i. e*, in motion) to its original condition.

These examples may *seem* hardly worth notice, nevertheless they should receive careful attention as important problems, viz., designing Structures *to resist impact*, can *only* be solved through these considerations. These problems will appear in the sequel.

474. Total Energy.—The Total Energy of a system is the sum of its Potential and Kinetic Energies.

475. Conservation of Energy.—This is a principle which has only recently been thoroughly established, and is considered one of the greatest discoveries of late years. The principle is that

* Todhunter's "Mechanics for Beginners," Chapter XVII., 2nd Ed.

"The Total Energy of a system though alterable in kind is indes-"tructible in amount by any *mutual action* of the parts of the system "itself," *i. e.*, "the Total Energy is a constant quantity".

In strictness this is only true when *every form* of Energy is included in the term "Total Energy," including therefore Heat, Electricity, &c. among the *components* of the "Total Energy."

In practical Engineering of Structures, the only form of Energy that requires to be considered is that of such *motion* as is visible, viz., such as is treated of in Elementary Dynamics, and the *quantity* of such *visible* motion as is *transformed* into other forms of motion, such as Heat, Electricity, &c., is so *small* that the principle of the "Conservation of Energy" is *approximately* true for these visible motions. This is a *very important* simplification of Engineering problems which would otherwise be extremely complex, and not completely reducible in the present state of science.

This principle is of great use in designing Structures to resist impact.

476. Suddenly Applied Load.—The following theorem is of such great importance that a rigorous demonstration will be given.

Theorem.—"The Work done by a Load gradually increasing from zero "to the amount W whilst moving through the whole space s is equal "to *half* the Work done by the same Load W *suddenly* moved through "the same space s.

N.B.—It is for this reason that the "Factor of Safety" for Live Loads which change rapidly, *see* Art 457, (and are therefore akin to sudden Loads) is made twice that for Dead Loads. This reason will be better understood after reading the Chapters on Elasticity, and Transverse Strain.

Proof. Divide the whole Load W and also the whole space s into a very great number n of very small equal parts (each of which will, therefore, be $W \div n$ and $s \div n$). Suppose for an instant that W increases from zero to W by *sudden* additions of these equal parts $\frac{W}{n}$ as the partial Load describes each division $s \div n$.

Then the Work *actually* done by the Load when it has attained any magnitude as $m\frac{W}{n}$ whilst passing with *gradual* increment of $\frac{W}{n}$ through the next space $\frac{s}{n}$ will be *intermediate* to the Work done in the two following

cases viz., $\frac{mW}{n}$ moved through $\frac{s}{n}$, and $\frac{m+1}{n}\cdot W$ moved through $\frac{s}{n}$, *i.e.*, (by definition of Work) intermediate to $\frac{mW}{n}\cdot\frac{s}{n}$ and $\frac{m+1}{n}\cdot W.\frac{s}{n}$.

Similarly the Work *actually* done by the *gradually increasing* Load W moving through the equal spaces $\frac{s}{n}$ from starting is intermediate for each space to the quantities written below the number of that space.

Space No.	1	2	3	4	...	...	...	$n-1$	n
Work done by Load at beginning of each space.	$o.\frac{s}{n}$	$\frac{W}{n}.\frac{s}{n}$	$\frac{2W}{n}.\frac{s}{n}$	$\frac{3W}{n}.\frac{s}{n}$	...	...	...	$\frac{n-2}{n}.W.\frac{s}{n}$	$\frac{n-1}{n}W.\frac{s}{n}$
Work done by Load at end of each space.	$\frac{W}{n}.\frac{s}{n}$	$\frac{2W}{n}.\frac{s}{n}$	$\frac{3W}{n}.\frac{s}{n}$	$\frac{4W}{n}.\frac{s}{n}$	...	...	...	$\frac{n-2}{n}W.\frac{s}{n}$	$\frac{nW}{n}.\frac{s}{n}$

∴ *Whole Work actually done by the gradually increasing Load is intermediate to the sum of these two, i.e.*, intermediate to

$$\left(o+\frac{W}{n}+\frac{2W}{n}+\dots\dots\dots\dots+\frac{n-1}{n}.W\right)\frac{s}{n}, \text{ and}$$
$$\left(\frac{W}{n}+\frac{2W}{n}+\frac{3W}{n}+\dots\dots\dots\dots+\frac{nW}{n}\right).\frac{s}{n}.$$

i.e, intermediate to $\left(o+\frac{n-1}{n}.W\right)\frac{n}{2}.\frac{s}{n}$, and $\left(\frac{W}{n}+\frac{nW}{n}\right)\frac{n}{2}.\frac{s}{n}$,

i.e., intermediate to $\left(1-\frac{1}{n}\right).\frac{Ws}{2}$, and $\left(1+\frac{1}{n}\right)\frac{Ws}{2}$, which approach to equality as n is indefinitely increased, viz., to $\frac{Ws}{2}$, *i.e.*, ultimately,

Whole work done by the gradually applied Load is $\frac{Ws}{2}$, ... (12).

But $\frac{Ws}{2}$ is by definition the "Work done" by the Load $\frac{W}{2}$ moved through the space s. Thus the theorem is proved.

This Theorem may be also thus expressed.

Theorem. "The Work done by a Load W moved suddenly through "the space s is *twice* that done by the same Load increasing gradually "from zero to the whole W moved through the same space s".

The Student of Integral Calculus will see that the above proof is really equivalent to the following,

"Work done" by the Load dW moved through the space ds is (by definition) $dW\,ds$

$\therefore$ Whole "Work done" by the gradually applied Load W through space s is

$$\int_0^W \int_0^s ds \,.\, dW = \int_0^s W.\, ds.$$

But since the Load is supposed to be uniformly-varying with the space $\therefore W = ws$ where w is a constant.

$\therefore$ Whole work $= \int_0^s ws\, ds = \frac{ws^2}{2} = \frac{Ws}{2}$ as before.

477. Resilience or Spring is the "Work" *absorbed* by or "Energy" *stored* in a Piece of Material during the act of producing a *given* Strain or Stress in it by a certain Load. On the removal of the Load, (if within the proof Load), this "Work" or Energy will be expended, or "restored," *i. e.*, visibly reproduced in effecting the recovery of figure of the Piece in consequence of the Elasticity of the material, so that the Work originally expended by the Load is really absorbed, or its Energy *stored* in the strained Material in the form of "Potential Energy" *i. e.*, Energy not producing *visible* motion, but possessing the *power* of so doing under certain conditions, (in this case the removal of the Load, *see* definition of Potential Energy, Art. 473). The use of this term is more fully explained in Chapter XXIV. on Elasticity.

Note to Art. 471.—

N.B.—Statical Moments are often measured in compound units bearing the same names (*e. g.* foot-pounds, inch-pounds, &c.) as the Dynamical Work-units. The two units are of course quite different in *kind*, and not therefore comparable. A homely instance of this kind is that of pounds sterling, and pounds avoirdupois, which differ from each other in kind.

CHAPTER XXII.

TENSION.

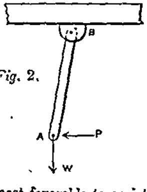
478. Tensile Strain, *i. e.*, Elongation or Extension, is produced by external forces, *i. e.*, by a *Load* in the direction of the strain, which tends to stretch or tear apart particles of the material in mutual contact, and produces *Tensile Resistance* and *Stress* between those particles.

All three, viz., the *Load*, the *Strain*, and the *Stress* are in the same direction, viz., perpendicular to the surfaces of particles of the material strained that are in mutual contact, so that their essential character is normal to those surfaces.

479. Theory indicates that *in homogeneous material* under a Load *of uniform intensity* per unit of area, (in which case the Resultant of the Load coincides with the axis of figure of the material strained,) the *Resistance to Tensile Strain, i. e.*, the *Tensile Stress* produced is directly proportional to the area of cross-section (perpendicular to the strain or stress) of the material strained, and constant for any one area of the same material. Experiment and practical experience abundantly confirm this theoretical consideration, when the materials used are nearly homogeneous.

480. It is very important to notice that the state of *Tensile Strain* is one *of stable equilibrium, i. e*, the tendency of the external applied forces or Load is to correct any trifling deviations, by whatever cause produced, after the removal of that disturbing cause: this is sufficiently evident from the annexed figure.

Fig. 2.



AB is a bar hanging vertically from B, stretched longitudinally by a weight W. If it be slightly pushed out of its vertical position *temporarily* by *any* cause, it clearly tends *to return to that position* on the removal of the disturbing cause.

This is important, because it follows that the tendency of the Load (or external applied forces) is to preserve the position of the bar in that originally assigned to it, which should be that most favorable to resistance.

481. The Algebraic expression of the law of resistance, just stated, is as follows (*see* Art. 461,) :— Let

A = *Net* Area (in square inches) *of least cross section* of material stretched (taken perpendicular to the stress), *i. e.*, deducting all holes, (*e. g.*, rivet and bolt holes) and flaws (*e. g.*, knots in timber).

P = Breaking Weight (in pounds), *i. e.*, Total Weight uniformly distributed over the area A which *will just break* the piece of material (by stretching).

= Ultimate Strength, *i. e.*, Ultimate Resistance to tearing (from the equilibrium).

= Ultimate Tensile Stress (by definition).

$\therefore$ $P \div 2240$ = the same in tons.

W = Working Load (in pounds), *i. e.*, Total weight uniformly distributed over the area A that the material can bear safely.

= Working Strength, *i. e.*, Working Resistance to stretching (from the equilibrium).

= Working or Safe Tensile Stress (by definition)

$\therefore$ $W \div 2240$ = the same in tons.

f_t = Modulus of tearing of the material (by definition).

= Weight in pounds that will just break (by stretching) a piece of the material of one square inch in section (by definition).

= Ultimate resistance to stretching *in pounds per square inch* (from the equilibrium).

N.B.—f_t is a *constant for each material* to be determined by experiments on direct stretching, and calculated by inversion of formula (1), thus $f_t = P \div A$. A table of its values for common building materials is given in Appendix II., and for Indian Woods in the List of Indian Timber Trees in Chapter V. Section I.

s = factor of safety applicable to the material, an empirical quantity fixed by experience (*see* Art. 457, and Table on next page).

$\therefore f_t \div s$ = safe intensity of tensile stress *in pounds per square inch* (by definition).

s_t = safe intensity of tensile stress *in tons per square inch* $= \frac{f_t}{2240} \div s$.

N.B.—These are two useful modifications of the co-efficient f_t.

$f_t \div s$ averages 1000 for timber for dead loads

s_t averages $1\frac{1}{2}$ for cast-iron for dead loads.

s_t " 7 for wrought-iron* for dead loads.

* This value is higher than that usually given: it is given on authority of Unwin's "Wrought-Iron Bridges and Roofs," 1869, Art. 32.

Factors of Safety *for Tensile Strain.	Proof.	Working.				
		$s = \frac{\text{Breaking Load}}{\text{Working Load}} = \frac{P}{W}$				
		Character of Load.				
	$\frac{\text{Breaking Load}}{\text{Proof Load}}$	Temporary.	Permanent, Dead.	Slight shocks or Vibrations as in Girders.	Sudden shocks as in Cranes.	Machinery.
Timber, ...	..	4	10	..	..	..
Cast-iron, ...	3	..	4?	6	..	..
Wrought-iron, ...	3	..	..	4	6	8
Steel (tough), ...	2	..	..	4?	..	..
Cordage, ...	..	3	4	..	..	..
Chain, stud, ...	..	..	..	..	3	..
Chain, close link, ...	2	..	3	..	4	..
Wire-rope, ...	..	..	7	9	..	..

Hence $P = sW$, and $P \div 2240 = s\,(W \div 2240)$ by def. .... (1).

And by the laws of resistance just given, for *Load* P or W of uniform intensity, ... $\Big\}\; P = f_t \cdot A$ .... (2).

Equations (1) and (2) contain all that is necessary for finding either the *Breaking Load* (P), or *Working Load* (W) of a piece of given cross-sectional area (A), or the converse, viz., to find the *least net cross-sectional area* (A) required to bear a *Working Load* (W) or *Breaking Weight* (P), in each case when the Load is uniformly distributed over the area (A).

482. Equation (2) is approximately true when the Load is *nearly* uniformly distributed over the area (A). In most cases in which Resistance to direct Tension has to be considered *in practice*, the Load is *approximately uniformly distributed*, and the formula (2) is sufficiently accurate for practical purposes. This is important, as this formula is *extremely simple* whereas the accurate formula for uneven distribution of Load is *complex*. Moreover the *full* powers of resistance of material to tension can *only* be utilized when the material is so arranged that the Stress is uniformly distributed over the area A (in which case the Resultant Stress of course

* From Stoney's "Theory of Strains," Chapter XIV.

Their *general* properties are as follows:—

(1). *Fibrous* materials are in general much stronger in resistance to tensile strain in the direction of the fibres than in any other direction, and also in general stronger than materials of the other classes. They generally yield considerably before fracture, thereby giving some sort of warning long before the point of fracture, a valuable property in materials for use in building and manufactures.

In consequence of the greater strength being in the direction of the fibres, the most numerous experiments for determining f_t are for that direction, and when not otherwise stated recorded values of f_t must be understood to refer *solely to that direction.*

For all these reasons *fibrous* materials should always be used if possible to resist tensile strain, and with their fibres in the direction of the strain.

Examples.—Woods, Wrought-iron, Rolled Metals, Wires, Ropes, Leather.

(2). Crystalline and (3) Quasi-Homogeneous Materials are in general comparatively weak in resistance to tensile strain; they are roughly speaking equally strong in all directions, yield little and *irregularly* under tensile strain before fracture, and consequently give little warning before fracture. For these reasons they should if possible not be subjected to tensile strain.

Examples of (2). Cast metals, some sorts of stones.

Examples of (3). Mortars, some sorts of stones, bricks.

485. Materials.—The materials usually subjected to tensile strain are—

(1). In Building—Iron, Wood.

(2). In Manufactures—Cord, Rope, Leather, Metals.

The following is an epitome of their principal properties in reference to *tensile strain*, (Arts. 186 to 192).

486. Cast-iron.—Cast-iron is liable to air holes, and flaws, and to unequal contraction in cooling, so that it is *permanently* irregularly strained, and is *quite unsuited to resist tensile strain.*

(1). Cold-blast iron is stronger than hot-blast.

(2). Re-melting, and also prolonged fusion (especially in soft-irons) *somewhat increase* the strength.

(3). Annealing diminishes the strength.

(4). Thick castings are proportionately stronger than thin ones.

(5). The interior of a casting is weaker than the exterior.

(6). Unequally distributed stress *greatly* reduces the *available* strength *e.g.*, Mr. Hodgkinson states* that "the strength of a rectangular piece of "cast-iron, drawn along the side is about $\frac{1}{3}$, or a little more, of its strength "to resist a central strain."

487. WROUGHT-IRON is well suited to resist tensile strain: its tenacity (f_t) is about thrice that of cast-iron.

STEEL is of very variable quality: soft steel is well suited to resist tensile strain.

(1). Rolled iron is stronger than forged: large forgings are stronger than small forgings, bar than plate, and common plate than boiler plate.

(2). Plate iron is about one-tenth stronger lengthways than crossways.

(3). Re-heating, hammering, and working improve wrought-iron to a certain point; good plate iron is worked to about the maximum degree of efficiency.

(4). Annealing reduces the strength (especially of wire).

(5). Removing the outer skin does not (as was formerly supposed) decrease the strength.

(6) Square rods are slightly stronger than round.

488. Kirkaldy's Conclusions.—Mr. Kirkaldy conducted a very extensive Series of Experiments on the *tensile strength* of wrought iron and steel, and deduced many practical conclusions which are recorded in the works below† quoted, and deserve the careful consideration of the Student These are too numerous to be reproduced *in extenso* in this Treatise, but a few of the most practical may be here quoted.

1. The breaking strain does *not* indicate the quality, as hitherto assumed

2. The contraction of area at fracture, previously overlooked, forms an essential element in estimating the quality of specimens (of both Iron and Steel)

3 Iron is injured by being brought to a white or welding heat, if not at the same time hammered or rolled

4 Iron is less liable to snap the more it is worked and rolled

5 Iron highly heated and suddenly cooled in water is hardened, and the breaking strain, when gradually applied, increased, but at the same time it is rendered more liable to snap.

6. Iron, like steel, is softened, and the breaking strain reduced, by being heated and allowed to cool slowly.

7. Steel is reduced in strength by being hardened in water, while the strength is vastly increased by being hardened in oil. The higher steel is heated (without, of

* Experimental Researches, page [illegible]12.

† Experiments on Wrought-Iron and Steel, D. Kirkaldy, 1863, and Stoney's Theory of Strains.

most favorable to resistance to great stress, (viz , nearly along the line of stress,) but *increases* the *practically available* Working Strength, as the closing of the sides of the links renders the chain rigid and therefore useless. Fracture usually occurs *at* the stay pin.

(2). *Close-link*, or *Crane Chain*, is that ordinarily used in machinery: it is, though liable to kinking, more flexible than stud chain. Fracture generally occurs after the sides of the links have closed, (so that the chain becomes rigid and useless), at the crown of a link.

(3). *Open-Long-link*, or *Buoy Chain*, is that chiefly used for mooring purposes where great flexibility is unnecessary. Each link has parallel sides: this chain is lighter than stud chain by the omission of the stay pins.

Chains of each sort are made in 15-fathom lengths: Stud-chain, and Close-link Chain have one open-long-link at each end, so as to admit of the 15-fathom lengths being joined by a shackle. In open-long link Chain, if one link break, *that link alone* can be replaced with the aid of shackles; whereas if Stud-chain or Short-link Chain break, *a whole 15-fathom length* must be removed, as there is not room to pass a shackle through their links.

The Proof and Working Stress-Intensities (*in tons per square inch of both sides* of the links) are given below,* with other data: it is believed that the Government Proof is insufficient, as much chain is believed to be passed which is not much stronger than the Proof applied. The Trinity test is more severe, and requires extremely good iron It is considered that the Working Stress should not exceed one-half the Proof Stress

	Weight in tons per fath d = diameter in inches.	Ultimate strength in tons per square inch = f_t — 2240	Proof Stress Intensity in tons per square inch.	Working Stress Intensity in tons per square inch	Relative Weights of same length. Equal ultimate strength.	Relative Weights of same length. Equal working strength.
Bar-iron, ...	007d^2	24	12	6	100	100
Stud-chain, ...	0245d^2	16	11 5	5 7	262	184
Close-link chain,..	028d^2	16	7 6	3 8	300	314
Long-link chain,..	..	..	5 7 to 8 5	2 8 to 4 25	..	..
Hemp cordage, hand made, .	·0111d^2	2 51	.	·63	150	150

* From Stoney's Theory of Strains, Chapter XIV.

CHAPTER XXIII.

COMPRESSION.

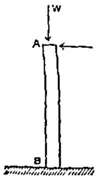
499. Compressive or **Crushing Strain,** *i e.*, CONTRACTION, is produced by external forces, viz., by a *Load in the direction of the Strain* which tends to compress or crush together particles of the material in mutual contact, and produces *Compressive* or *Crushing Resistance* and *Stress* between those particles.

All three, viz , the *Load*, the *Strain*, and the *Stress* are in the same direction, viz., perpendicular to the surfaces of particles of the material strained that are in mutual contact, so that their essential character is normal to those surfaces.

500. Theory indicates that, *in homogeneous material, under a Load of uniform intensity* per unit of area, (in which case the Resultant of the Load coincides with the axis of figure of the material strained,) the laws of resistance to "*direct compression*" would be exactly the same as those of resistance to direct tension, *q v*, and expressible by the same simple algebraical formula, viz , $P = f_c \cdot A$, (Art. 481, Equation (2)).

501. It is, however, very important to notice that the state of *Compressive Strain* is one *of unstable equilibrium*, *i. e*, the tendency of the external applied forces (or Load) is to *increase* any trifling deviations produced by any cause whatever after the removal of that disturbing cause: this is sufficiently evident from the annexed figure.

Fig. 4.



[AB is a vertical pillar fixed at the foot more or less perfectly, and strained longitudinally by the weight W. If it be slightly pushed out of its vertical position even temporarily by any cause, the Load tends to make it deviate yet further; partly by increasing the inclination of the pillar as a whole to the vertical if not originally immovably fixed at B, and partly by bending of the pillar throughout its length, even after the cessation of the disturbing cause.]

In practice it is impossible to secure the exact co-incidence of the Re-

sultant of the Load with *the axis of figure* of the strained material, indicated as desirable; it is nevertheless *very desirable* to adjust the material, especially *in the neighbourhood of the joints* or points of application of the external forces, so as to secure the approximate co-incidence of these two lines, as otherwise the full powers of resistance of the whole material cannot be utilized; as will be explained below (Art. 507 (b)). But even when this is secured, it follows, in consequence of the state of strain being one of unstable equilibrium, that any temporary deviation has a tendency to increase, thus causing *additional strain* due to *flexure* of the material, (*i. e.*, of a different character, viz., Transverse Strain,) which will moreover *increase with the length* of the material.

502. It follows that resistance to pressure is *a complicated phenomenon* compared to resistance to stretching, and that its laws probably cannot be expressed by any *very simple* formula.

Experiment and practical experience abundantly confirm this.

503. The results of experiment may be thus summarized.

Def. A piece of material under compressive strain will be called for brevity a "Pillar."

It appears (from experiment) that "Pillars" may for the present purpose be classified as follows, according to their manner of failure under compression, or according to the values of the ratio $l \div d$ (for explanation of symbols, *see* Notation, Art 504), which seems to determine their mode of failure.

I. "Very short" Pillars, ($l \div d < 1\frac{1}{2}$)· these give way irregularly.

II. "Short" Pillars, ($l \div d > 1\frac{1}{2}$ but $<$ from 5 to 10): these alone give way apparently actually by "*direct crushing*" of the material.

III. "Long" Pillars, ($l \div d >$ from 5 to 10 but $<$ than in Class IV.): these give way partly by "direct crushing" as Class II., partly by bending as Class IV.

IV. "Very long" Pillars, ($l \div d >$ from 15 to 30 when the ends are free, and $>$ 30 to 60 when the ends are fixed): these give way by *bending*.

[*N B.*—The term "direct crushing" is applied only to Class II.; the term "crushing by flexure" is applied only to Classes III. and IV.

Pillars will be distinguished for brevity in this Treatise simply as "Very Short," "Short," "Long," "Very Long"]

The formulæ applicable to each case are *different*, and must be separately discussed.

504. Notation.—The following notation will be used uniformly, (compare Art. 461).

l = length of pillar (in inches) } both measured parallel to the stress,
L = " (in feet) } ∴ $L = l \div 12$.

A = *gross area* (in square inches) of *the least cross section* of the pillar taken *perpendicular to the stress, i. e.*, ⊥r to l or L.

[*N.B.*—By "gross area" is meant area of *solid* material only, without deduction for any holes, such as key, rivet, or bolt-holes, provided these holes have been completely and solidly filled up by solid keys, rivets, or bolts of the same quality of material as the material of the pillar.

This condition is usually satisfied in practice, so that deduction for such holes is seldom necessary in calculation].

d = *least external* depth or width (in inches) *of that* cross section, viz., of A.

[*N.B.*—In a complex cross section, such as is common in iron-work, d is to be taken as *the least width* of the least simple figure, (viz , triangle, square, or rectangle) that can be drawn round that cross section. This is Rankine's* rule, *see* Art. 520].

t = thickness in inches of a *hollow* pillar.

P = *Breaking Weight* (in pounds), *i. e.*, *Total Weight*, distributed as afterwards described, that *will just break* the pillar by crushing.
= *Ultimate Strength, i. e.*, *Ultimate Resistance* to crushing (from the equilibrium).
= *Ultimate Stress* (by definition),
∴ P ÷ 2240 = the same in tons.

W = *Working Load* (in pounds), *i. e.*, *Total weight*, distributed similarly to P, that the Pillar can bear *safely*.
= *Working Strength, i. e.*, *Working Resistance* to crushing (from the equilibrium).
= *Working* or *Safe Stress* (by definition).
∴ W ÷ 2240 = the same in tons.

f_c = *Modulus of crushing* of the material.
= Weight (in pounds) that will just break by "direct crushing," (*see* Class II.,) a "short pillar" of the same material of one square inch in section (by definition).
= *Ultimate Resistance* to "direct crushing" in pounds per square inch (from the equilibrium).

N.B.—f_c is *a constant for each material* to be determined by experiment.
A table of its values for common building materials is given in Appendix II., and for Timber in Chap. V., Section I.

* "Manual of Civil Engineering," by W. J. M. Rankine, Art. 158, 6th Ed

Its value is calculated from the equation (2) below for "Short Pillars," (by inversion) thus $f_c = P \div A$.

s = factor of safety applicable to the material, an empirical quantity fixed by experience, (*see* Art. 457 and Table below.)

$\therefore f_c \div s$ = *safe* intensity of crushing stress in pounds per square inch (by definition).

s_c = intensity of crushing stress in tons per square inch $= \frac{f_c}{2240} \div s$.

N.B.—There are two very useful modifications of the coefficient f_c; (*See* Art. 533)

$f_c \div s$ averages 1000 for timber for dead loads.
s_c ,, 10 for cast-iron ,,
s_c ,, 4½ for wrought iron* ,,

Factors of Safety under Crushing Strain.	Proof. Breaking Load / Proof Load	Working. $s = \frac{\text{Breaking Load}}{\text{Working Load}} = \frac{P}{W}$ Character of Load. Temporary	Permanent as in girders	Subject to shocks and vibrations as in bridges	Heavy shocks and vibrations as in Machinery.
Rock (in foundation), ...	.		8	...	...
Cut-stone, *e. g.*, Arch Voussoirs and Pillars,	...	...	20	...	...
Brickwork, Concrete, Rubble, ...	...	...	6	...	...
Timber (dry), ...	...	4	10	...	...
Cast-iron, ...	3	..	5	6	10
Wrought-iron, ...	3	...	4	6	10

505. The formulæ about to be given all give the Breaking Weight of the Pillars in question. By combining them with the equation which connects the Breaking Weight and Working Load, viz.,

$P = sW$ (by definition), also $P \div 2240 = s\,(W \div 2240)$, ... (1),

the Working Load W can be found when A is given, or conversely A the area of pillar required to carry safely a given Working Load W can be found.

As their convenient application requires some care, examples will be given at the end (Art. 532, *et seq.*).

506. Class I.—"Very Short Pillars," ($l \div d < 1\frac{1}{2}$); these give way

* This value is higher than usually given: it is quoted thus on authority of Unwin's "Wrought-Iron Bridges and Roofs," 1869, Art. 82.

From Stoney's Theory of Strains, Chap. XIII., and Rankine's Civil Engineering.

irregularly, and offer enormous resistance to crushing, the law of which *has not yet been formulated.* The probable reason for the enormous amount of resistance of such pillars is* that the external portions confine the inner portions, and so prevent the interior at any rate from giving way in the same manner as in Class II.

[*N.B.*—No formula being extant for the strength of "Very Short Pillars" the strength may be approximated to very roughly as somewhat greater than that calculated from the formula (2) for Class II., (*q. v.*)]

507. Class II.— "Short Pillars" which give way apparently by "*direct crushing*" of the material, ($l \div d > 1\frac{1}{2}$, but < 5 for cast-iron, and < 10 for wrought-iron, steel, and timber).

Two cases should be *distinguished*—

(*a*). Load uniformly distributed over the area A. } See Notation, Art 504.
(*b*). Load unequally " " }

Case (*a*). *Load uniformly distributed over the area* A. Theory indicates that, in homogeneous material under an external load of uniform intensity per unit of area of any cross section, (in which case of course the Resultant of the Load co-incides with the axis of the pillar), the *Total Resistance* to crushing at that section, *i. e.*, *Total Crushing Stress* at that section, should be (1) directly proportional to the area of that section, and (2) constant for any one section of the same material.

Experiment and practical experience confirm this theoretical conclusion, when the Pillars are so *short* that their full powers of resistance to "direct crushing" can be utilized, viz., when not long enough to be liable to *bend*, *i. e.*, in the case of "Short Pillars" only.

As it is impossible in other cases to utilize the full powers of resistance to direct crushing of the whole of the material, the term "direct crushing" is now applied to this case only.

The Algebraic expression of the law of resistance just set forth is

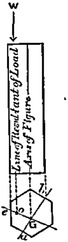
$$P \equiv f_c \,.\, A, \text{ (see Notation, Art. 501) } \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

Case (*b*). *Load unequally distributed over the area* A. If the Load be *unequally distributed* over the area A of least cross section (perpendicular to the Stress), the Resultant of the Load deviates from the axis of the pillar, and *the centre of pressure* on the area A deviates from *its centre of figure*, and the Stress over the area is *of varying intensity*. Now as the Strength of materials depends on the *greatest* (not on the mean) intensity

* "Theory of Strains in Girders," by B. B. Stoney, Art. 379, 2nd Ed.

of stress, it follows that the Strength of a Pillar is *reduced* by unequal distribution of the Load in the *ratio* of the mean intensity to the greatest intensity of stress. This ratio may be found with sufficient accuracy by considering the Stress as *uniformly varying* (*i.e.*, of intensity at any point in the cross-section A proportional to the distance of that point from the "neutral" axis of the cross-section).

Fig. 5.



Thus let x_0 = greatest deviation *in inches* of the centre of pressure o from the centre of figure G of *any* cross-section A, *i.e.*, the *greatest* deviation of the Resultant of the Load from the axis of figure of the pillar.

= oG in the figure.

x_1 = distance *in inches* of the point of greatest stress, viz., e, from the axis of the pillar; the point e is found as the point in which Go cuts the boundary of the cross-section: thus x_1 = Ge.

I = "Moment of inertia" of the cross-section A relative to *its neutral axis ab* which is "conjugate" to the line oG.

[The method of finding the position of this neutral axis *in general*, and of finding the value of I relative to it is beyond the scope of this Treatise. It is fully explained in Rankine's Manual of Applied Mechanics, Arts 285 and 95.]

Then it may be shown* that the ratio in which the pillar is *weakened* by unequal distribution of the Load is

$$\frac{\text{Mean intensity of stress}}{\text{Maximum intensity of stress}} = 1 \div \left(1 + x_0 \cdot \frac{x_1 A}{I}\right) \quad \ldots\ldots\ (3).$$

The Breaking and Working Loads P and W are of course both reduced in the same proportion, *i. e.*, (*see* Notation, Art. 504.)

$$P = f_c \cdot A \div \left(1 + x_0 \cdot \frac{x_1 A}{I}\right) \quad \ldots\ldots\ (4).$$

In order that this formula may be available without the difficulty of finding the value of I, and without further reference, the values of the quantity $\frac{x_1 A}{I}$ for some symmetrical forms of cross section of common occurrence are here given.

In each case the deviation (x_0) is supposed to take place along an axis of symmetry of the cross-section, from which it follows that the neutral axis

* *See* Rankine's Manual of Applied Mechanics, Art. 285.

is, in each case, that axis of symmetry which is at right angles to the deviation Go : *e. g.*, in rectangles the neutral axis joins the middle points of two parallel sides, in an ellipse it is one axis, &c.

For cases not included in the Table, reference must of course be made to some larger work, (*e. g.*, Rankine's,) to determine the value of I.

Cross section.	Dimensions.	Position of neutral axis $\perp^r$ to deviation x_0 passes through G	Value of $\frac{x_1 A}{I}$
Rectangle, Square,	Sides b, d, Sides d,	Parallel to b, Parallel to d,	$\frac{6}{d}$.
Ellipse, Circle,	Axes d, b, Diameter d,	The axis b, A diameter,	$\frac{8}{d}$.
Hollow rectangle,	External sides b, d, Internal sides b', d',	Parallel to b,	$6d \cdot \frac{(bd - b'd')}{(bd^3 - b'd'^3)}$.
Hollow square,	External sides d, Internal sides d',	*Parallel to d,*	$\frac{6d}{d^2 + d'^2}$.
Circular ring,	External diameter d, Internal diameter d',	A diameter,	$\frac{8d}{d^2 + d'^2}$.

It will be evident from comparing this table with the formula (4), that the *reduction* of Strength in consequence of unequal distribution of Load *may be very considerable,* and the importance of adjusting the Load, so as to be nearly uniformly distributed over the cross-section of Pillar (in which case *the Resultant of the Load and axis of the Pillar will nearly co-incide)* will now be evident (*see* also Ex. 2, Art. 533).

It may not *always* be possible to effect this, but it is very advisable in large Masonry Structures to limit the deviation (x_0) of the centre of pressure from the axis of the Pillar so that there shall be no *tension* in any part of the cross section (*see* Art. 492). This condition is attained when the *least* intensity of pressure is positive or zero, in which case the *greatest* intensity of stress will be *not more than twice* the mean intensity, so that P not $> f_c \cdot A \div 2$, from which it follows (from equation 4), that x_0 is not $> I \div x_1 A$, the reciprocal of which is tabulated above.

508. Application of formulæ (2) and (4). Formulæ (2) or (4), each combined with equation (1), give the Breaking Weight (P) and Working Load (W) of a "Short Pillar" of *least* cross-sectional area A, or conversely the *least* cross-sectional area A of a "Short Pillar" which will just break under a Load P, and carry *safely* a Working Load W.

[*N.B.*—In the latter (which is the most useful application), care must be taken to ascertain *after finding* A that the Pillar in question really is a "Short Pillar," i. e., that $l \div d$ falls within the prescribed *limits*, as the formulæ are otherwise quite *inapplicable*].

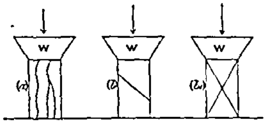
Formula (2) is *strictly* applicable only when the Load P or W is *uniformly distributed* over the least cross-section A taken perpendicular to the Stress (in which case of course the Resultant of the Load and axis of the Pillar co-incide at that section). In practice, however, if the Load is nearly uniformly distributed, the approximate co-incidence (already pointed out as so desirable) of these two lines is secured, and the formula (2) is *sufficiently accurate for practical purposes.*

[*N.B.*—This is important, as this formula (2) is extremely simple, whereas the accurate formula (4) for a load unequally distributed is complex.]

509. Mode of Failure of "Short Pillars."—Different kinds of material give way by *direct crushing* in different ways according to their molecular structure, thus—

(*a*). *Crushing by splitting, Fig.* 6 (*a*), into a number of prismatic bits, separated by tolerably regular surfaces, whose general directions are roughly parallel to the Stress, characterises hard homogeneous substances of a glassy texture, *e. g.*, vitrified bricks.

Fig. 6.



(*b*). *Crushing by shearing* or sliding of portions of the blocks along *oblique* surfaces of separation, characterises substances of a granular texture, *e. g.*, cast metals, stone, brick.

Sometimes the sliding takes place at a single plane surface, *Fig.* 6 (*b*); sometimes two rude cones are formed, which in their approach drive out-

wards a number of wedge-shaped portions *Fig.* 6 (*b'*). The surfaces of shearing make an angle with the direction of the Stress which varies with the material, (*e. g.*, from 32° to 42° for cast-iron), showing that the resistance to shearing is not a purely cohesive force, but consists partly of a force similar to friction, (which increases with the intensity of normal pressure); for a purely cohesive force would depend solely on the intensity of shearing stress which is known to be greatest* in planes inclined 45° to the direct crushing stress.

(*c*). *Crushing by bulging* or lateral spreading characterises tough and ductile materials, *e. g.*, wrought-iron and rolled metals. The bulging of such materials is so gradual, that it is difficult to measure resistance to this form of crushing.

(*d*). *Crushing by buckling or crippling* characterises fibrous materials under direct crushing stress *along the fibres;* it consists in lateral bending and wrinkling, and sometimes splitting of the fibres.

Example.—Timber, wrought-iron plates, wrought-iron bars.

General Remarks, on the various modes of failing by *direct crushing.*

(*a*) and (*b*), Materials which are crushed *directly*, (*a*) by *splitting*, and (*b*) by *shearing*, resist crushing far better than stretching, (see the tables of ultimate resistance to each,) *e. g.*, in cast-iron the Resistance to direct crushing, viz., $f_c = 6 \times f_t$ the Resistance to stretching. Materials of these two classes are therefore best fitted to sustain "direct crushing" stress; it follows that Cast-Iron is the best of all common Building Materials for use as a "Short Pillar."

(*c*). Materials which fail under "direct crushing" by *bulging* resist stretching better than crushing, *i. e.*, $f_t > f_c$.

Example.—In wrought-iron $f_c = \frac{2}{3} \cdot f_t$ to $\frac{3}{4} f_t$.

(*d*). Fibrous materials which fail under "*direct crushing*" by *buckling* resist stretching much better than crushing, *i. e.*, $f_t > f_c$ especially when the lateral adhesion of the fibres is weak compared with their tenacity.

Example.—In most *dry* timber $f_c = \frac{1}{2}$ of to $\frac{2}{3}$ of f_t.

510. Class III. **"Long Pillars"** which fail partly by "*direct crushing*" partly by "*bending*," and

Class IV. "Very Long Pillars" which fail by simple *bending.*

Three classes of formulæ known as Hodgkinson's, Rondelet's, and

* Rankine's "Manual of Civil Engineering," Art. 1[illegible].

Gordon's are in common use for expressing the strength of such pillars.

They are all modifications of the simple formula (2), (applicable only to *direct* crushing,) viz., $P = f_c A$, by a factor depending on the ratio $l \div d$, expressing the physical law that *the Strength decreases* (in consequence of the increased liability to flexure) *as the ratio* $l \div d$ *increases.*

They are as follows (For general Notation, *see* Art.504; special symbols are explained below) in general form.

Hodgkinson's, $P \div 2240 = C \cdot \frac{d^{3\cdot76 \text{ or } 3\cdot55}}{L^{1\cdot7 \text{ or } 2}}$, (*see* Art. 516).

Rondelet's, $P = k \cdot f_c A$, (*see* Art. 519).

Gordon's, $P = f_c \cdot A \div \left\{1 + c \cdot \left(\frac{l}{d}\right)^2\right\}$, (*see* Art. 520.).

With these should be combined in each case equation (1), $P = sW$ which connects the Breaking and Working Loads.

[*N.B.*—P and W are in all these formulæ supposed *uniformly distributed* over the *least* cross-sectional area A, taken perpendicular to the stress.

If the distribution of load is *nearly uniform*, the formulæ are *sufficiently accurate for practical purposes.* If not nearly uniform, P must be reduced in the ratio indicated in equation (4) This of course considerably complicates calculations, especially when the quantity to be found is A].

511. The following remarkable results of the experiments of Mr. Eaton Hodgkinson, (experimentally verified for Cast-iron, Wrought-iron, Steel, and Timber,) require particular attention before considering the formulæ in detail; viz., that

"The manner of fixing the ends of a Pillar materially affects its power of Resistance to crushing, if so long as to be liable to bend".

The ordinary modes of fixing the ends of a Pillar are three, viz.,

(1). Free at both ends.

(2). Free at one end, and firmly fixed at one end.

(3). Firmly fixed at both ends.

N.B.—A Pillar is considered *fixed* or *free* at its extremity according as the axis of the Pillar is, or is not, *immovably fixed in direction* at that end.

Ex.—(1). A Pillar rounded at one end is *free* at that end.

(2). A Bar pivoted with one round bolt or pivot, (*e.g.*, the compression-bars of a Warren Girder) is *free* at that end.

(3). A Pillar with a flat end firmly bedded is *fixed* at that end.

(4). A Bar firmly riveted with *several* rivets driven so as to fully fill the rivet holes is *fixed* at that end (*e. g.*, the compression-bars of a Lattice Girder).

The relative Ultimate Strengths of the *same* Pillar *differently fixed* as (1), (2), (3) *vid. supra* have *a simple mutual relation*, different however in Classes III. and IV., *q. v.*:—These Ultimate Strengths may be denoted by P_1, P_2, P_3. The results are expressed in equations (5), (6), (8), (9).

(512.) Class III. **"Long Pillars"** which fail partly by "direct crushing," partly by "bending."

Material.	Both ends free.	Both ends fixed.
Timber and Cast-iron, ...	$l \div d > 5 < 15$	$l \div d > 5 < 30$
Wrought Iron	$l \div d > 10 < 30$	$l \div d > 10 < 60$

The result of Mr. Hodgkinson's experiments on the relative Ultimate Strengths of "Long Pillars" differently fixed are as follows:—

Ultimate Strength (one end fixed, one end free) is approximately the arithmetic mean of the Ultimate Strength (both ends free), and Ultimate Strength (both ends fixed).

Ultimate Strength (both ends free) = $\frac{1}{3}$ to $\frac{2}{3}$ of Ultimate Strength (both ends fixed), the ratio increasing from $\frac{1}{3}$ to $\frac{2}{3}$ as the ratio $l \div d$ decreases,

i. e., $P_2 = \frac{1}{2}(P_1 + P_3)$ approximately .... (5).

$P_1 = \frac{1}{3} P_3$ to $\frac{2}{3} P_3$ .... (6).

No exact formula has been given for this last ratio. The above results are applicable of course to all three principal formulæ of Art. 510.

Hodgkinson's Formula for "Long Pillars" with both ends fixed.

513. Application of formula (7) and (7A)—This formula has the great disadvantage of being strictly applicable *only to the case of a Pillar fixed at both ends*, in consequence of the relation between the Ultimate Strengths of the same Pillars differently fixed not having been formulated.

It has the further disadvantage of involving both P_b and P_c, thus necessitating two calculations, (viz., P_b and P_c), when P is the quantity sought, and rendering the inverse problem of finding A or d (which is the *usual* one) nearly impossible (except by troublesome approximations) owing to the complexity of the equation in d which would involve $d^{3.76}$ or $d^{3.55}$ and *also* $d^{1.76}$ or $d^{1.55}$.

Its utility is further limited by the limitations to the formula for P_b (*q. v.*) *see* Class IV.

514. Class IV. **"Very Long Pillars"** *which fail by "bending."*

Materials.	Both ends free.	Both ends fixed.
Timber and Cast-iron, ...	$l \div d > 15$	$l \div d > 30$
Wrought-iron and Steel, ...	$l \div d > 30$	$l \div d > 60$

The result of Mr. Hodgkinson's experiments on the relative Ultimate Strengths of "Very Long Pillars" differently fixed are as follows:—

Ultimate Strength (free at both ends): Ultimate Strength (free at one end, fixed at one end): Ultimate Strength (fixed at both ends) $= 1 : 2 : 3$ approximately, for the *same* Pillar.

Also Ultimate Strength (free at both ends, length l) = Ultimate Strength (fixed at both ends, length $2l$) approximately,

i. e., $P_1 : P_2 : P_3 = 1 : 2 : 3$ · (for the *same* Pillar),..........(8).

P_1 (length $= l$) $= P_3$ (length $= 2l$),...... ....(9).

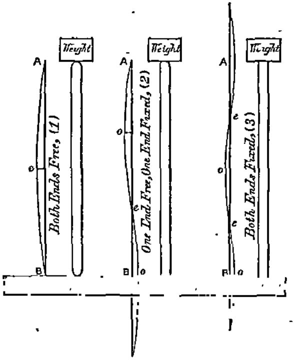
These results are of course applicable to all three principal formulæ of Art. 510.

[*N.B.*—Mr. Hodgkinson and Mr. Gordon have each given separate formulæ for determining P_1 and P_3, the Ultimate Strength of the pillar with the ends both free or both fixed, but the above simple relations render it unnecessary to commit more than one of each (preferably that for both ends fixed, viz., P_3) to memory, which, as these formulæ (to be given presently) are not very simple, is of importance].

The diagram *Fig.* (7) is considered to afford some explanation of the relative Ultimate Strengths of the *same* Pillar *differently fixed* being as in equations (5), (6), (8) and (9).

The curve assumed by the axis of each Pillar is drawn to its left, highly exaggerated: the Pillars are found to *break* at their points of greatest deflection *o* in the figure; thus a Pillar breaks in one, two or three places according as its ends are fixed as in (1), (2), or (3).

Fig. 7.



This affords some explanation of equations (5), (6), and (8).

Further the *effective* lengths of the Pillars as far as Resistance to *bending* is concerned are AB, A*e*, *ee* in Pillars (1), (2), (3), respectively: thus it appears that *fixing* either or both ends of a Pillar diminishes its *effective* length, *i. e. decreases* the ratio $l \div d$, and therefore *increases* its Strength.

Also, in Pillar (3) the effective length *ee* is found to be $\frac{1}{2}$ AB (by experiment). This affords some explanation of equation (9).

515. The following results of experiment on "Very Long" Pillars may be added.

(1). Discs added to the flat ends of Pillars (so as to increase their bearing) *increase* the Strength *very slightly*.

(2). Enlarging the cross-sectional area of Pillars near the middle *adds* about $\frac{1}{7}$th to the Ultimate Strength in *solid* pillars *free at both ends* (but *does not affect* pillars that are either *hollow* or *fixed at both ends*).

(3). *Square* Pillars yield in the direction *of their diagonals.*

(4). Pillars *irregularly* fixed at the ends are only as strong as Pillars free at the ends.

(5). The Ultimate Strength of *similar* Pillars is as their *least* cross-sectional area.

(6). The relative Strengths of Pillars of different materials are approximately as follows:—

Cast steel (not hardened), 25; Wrought-iron, 17; Cast-iron, 10; Dantzic Oak, 1; Red Deal, $\frac{4}{5}$.

N.B.—This shows that Wrought-iron is by far the most suitable common Building Material for use in the form of a "Very Long" Pillar.

It has been already remarked that Cast-iron is the most suitable for use in the form of a "Short Pillar." Cast-iron being a crystalline material, is ill suited to resist deflexion, and therefore ill suited for use as a "Very Long Pillar" (*see* Art. 525).

(7). A square is the strongest form of rectangular cross-sections of equal area: this is also evident from the fact that the Strength *increases* as the ratio $l \div d$ decreases: among such rectangles, d (being the *least* width) is greatest for a square.

516. Hodgkinson's formulæ for "Very Long Pillars".—(For Notation, *see* Art. 504).

Material of, and form of, Pillar.	Both ends free.	Both ends fixed.	Formula.
Cast-iron Solid Pillars.—Uniform Circular Section.	$\frac{P}{2240} = 14.9 \cdot \frac{d^{3.76}}{L^{1.7}}$	$\frac{P}{2240} = 44.16 \cdot \frac{d^{3.55}}{L^{1.7}}$	(10).
Cast-iron Hollow Pillars—Uniform Circular Section. ($d' =$ internal diameter).	$\frac{P}{2240} = 13 \cdot \frac{d^{3.76} - d'^{3.76}}{L^{1.7}}$	$\frac{P}{2240} = 44.34 \cdot \frac{d^{3.55} - d'^{3.55}}{L^{1.7}}$	(11).
Wrought-iron Solid Pillars—Uniform Circular Section.	$\frac{P}{2240} = 42.8 \cdot \frac{d^{3.76}}{L^{2}}$	$\frac{P}{2240} = 133.75 \cdot \frac{d^{3.55}}{L^{2}}$	(12).
Timber Solid Pillars—Uniform Rectangular Section.		$\frac{P}{2240} = C \cdot \left(\frac{d}{L}\right)^{2} \cdot A.$ C depends on the material.	(13).

C = 10.95 for Dantzic Oak, 7.8 for Red Deal, 6.9 for French Oak, (all dry).

As these formulæ are *empirical*, special attention should be paid to the *limits* of their applicability as regards the value of the ratio $l \div d$, the

form of cross-section, and manner of *fixing*. The values of the constant C (*see* Art. 510) in *all* these formulæ, as given by Mr. Hodgkinson, give the Breaking Weight *in tons:* to preserve uniformity of notation in this Treatise, P which is *in pounds* is therefore divided by 2240 (*see* Notation, Art. 504).

The formulæ are given in the form given by Mr. Hodgkinson; he, however, records his opinion* that the quantities $d^{3.76}$ and $d^{3.55}$ may both be replaced by $d^{3.6}$ with *sufficient accuracy;* this is important, as a table of 3·6th powers can thus be used for all the formulæ for iron. Tables of 3·6th and 1·7th powers are given in Appendix II.

Mr. Hodgkinson has also recorded his opinion that in *incompressible* material the quantities $d^{3.76}$ and $d^{3.55}$ would both be d^4, and $L^{1.7}$ would be L^2, so that the modification of the exponents of d and L appears to depend on the compressibility of the material.

517. These formulæ contain no symbolic factor to suit different forms of cross-section, and are therefore only *directly* applicable to the particular cross-section for which the constant C was determined by experiment, viz.,

For cast and wrought-iron,......Uniform circular cross-section.
For timber,..........................Uniform rectangular ,,

The following simple relations established by experiment between the Ultimate Strengths of "Very Long Pillars" of Cast-iron, enable these formulæ (10) to (13) to be applied to two other forms of cross-section, viz.,

The Ultimate Strength of "Very Long" *solid* Cast-iron Pillars *of the same quality, of the same length* and *of uniform cross-section* are for the following figures of cross-section.

(*a*), if *of equal cross-sectional area*, Circle : Square : Equilateral triangle = 10 : 9 3 : 11, ... (14).

(*b*), if *of equal breadth*—Circle : Square = 1 : 1·6 .... (15).

518. Application of formulæ (10) to (13).—These formulæ have the disadvantage of all empirical formulæ, *i. e., of limited application,* viz., only to a few forms of cross-section (stated in each case).

Those for iron have the disadvantage of requiring either the direct calculation of the awkward quantities $d^{3.76}$ or $d^{3.55}$ and $L^{1.7}$ or of the use of a table of such powers; this renders the solution of the inverse problem (the *usual* one) of finding d and d' nearly impossible (except by a trouble-

* "Experimental Researches on the Strength &c., of Cast-Iron," 1847, Arts. 39 and 62.

some approximation) in the case of a hollow Pillar, (which on account of its great power of resistance to "crushing by flexure" is a most useful form), unless *the thickness* of the metal *be very small* compared with the diameter d.

The solution in this case is as follows :—

Given P and L to determine d and t (thickness of metal in inches) in the case of a "Very Long Pillar" *fixed at both ends.*

By the formula $\dfrac{\mathrm{P}}{2240} = 44{\cdot}34\,\dfrac{d^{3\cdot55} - d_1^{3\cdot55}}{\mathrm{L}^{1\cdot7}}$

$$\begin{aligned}\text{But } d^{3\cdot55} - d_1^{3\cdot55} &= d^{3\cdot55} - (d - 2t)^{3\cdot55} \\ &= d^{3\cdot55} - d^{3\cdot55}\left(1 - \frac{2t}{d}\right)^{3\cdot55} \\ &= d^{3\cdot55} - d^{3\cdot55}\left(1 - 3{\cdot}55 \times \frac{2t}{d}\right) \text{ nearly,} \\ &= 7{\cdot}1 \times t\,d^{2\cdot55}\end{aligned}$$

by neglecting terms involving $\left(\dfrac{t}{d}\right)^2$, $\left(\dfrac{t}{d}\right)^3$, &c., since $\dfrac{t}{d}$ is very small.

$$\therefore \frac{\mathrm{P}}{2240} = 44{\cdot}34 \times \frac{7{\cdot}1 \times t\,d^{2\cdot55}}{\mathrm{L}^{1\cdot7}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (16).$$

whence t and d may be determined if either be given, or the ratio $\dfrac{t}{d}$ be given.

Notwithstanding the disadvantages of these formulæ, they are in high repute in consequence of their representing the result of a very extended series of experiments (*see* Ex. 4, 5, Art. 533).

519. Classes III. and IV.—**Rondelet's Formula,** applicable only to *simple timber posts.* (For Notation, *see* Art. 504).

$$\mathrm{P} = k \,.\, f_c\, \mathrm{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17).$$

This is purely an empirical formula: k is a quantity varying with the ratio $l \div d$: it is given by Rondelet* in the form of a numerical ratio for several values of the ratio $l \div d$, determined by experiments on *square* Oak and Fir Posts.

Ratio $l \div d$	12	24	36	48	60	72	
Value of k	$\frac{5}{6}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{12}$	$\frac{1}{24}$	

The only merit of this formula is its simplicity in application, especially when P is the quantity sought.

* Rondelet, "L'Art de Batir," 1812, page 222.

It has the *serious disadvantage* that the "state of fixation" of the ends of the posts for which the formula was adopted, is nowhere stated in Rondelet's Work, nor has this omission been supplied by later writers.

[From a comparison of this formula with Gordon's formula made by the writer of this Article, it appears probable that the formula is applicable to Pillars *with both ends fixed*, but the agreement between the formulæ is decidedly bad].

Further, when A is the quantity sought, (the *usual* problem,) the formula cannot be *successfully* used without a previous knowledge of the ratio $l \div d$ which involves the knowledge of d, one of the very elements sought, so that *in general* several trials must be made with different values of k, and the ratio $l \div d$ resulting from the value of d obtained by solution of the equation $A = P \div (k \cdot f_c)$ compared with the value of k actually used (*see* Ex. 3. Art. 533).

On account of these disadvantages probably, it has been left out of some recent important Works on Engineering.

520. Classes III. and IV.—**Gordon's formula** (universally applicable).

P uniformly distributed over the area A.

Both ends free.	One end free, one end fixed.	Both ends fixed.	
$P = \dfrac{f_c \cdot A}{1 + 4c\left(\dfrac{l}{d}\right)^2}$	$P = \dfrac{f_c \cdot A}{1 + \dfrac{16}{9}c\left(\dfrac{l}{d}\right)^2}$	$P = \dfrac{f_c \cdot A}{1 + c\left(\dfrac{l}{d}\right)^2}$	(18)

$c = \frac{1}{800}$ for cast-iron, $\frac{1}{3000}$ for wrought-iron,
$= \frac{1}{250}$ for dry timber, $\frac{1}{600}$ for stone and brick.

The simple relations in equations (8) and (9), *q. v.*, render it unnecessary to commit more than one of these to memory, (a matter of some importance,) but for convenience of application, especially when A is the quantity sought (the *usual* problem) it is *more convenient* to have them ready to hand without further reference, or reduction.

This formula was first proposed by Tredgold* *on theoretical grounds*; it fell into disuse probably in consequence of the experimental data for

* "Practical Essay on the Strength of Cast-iron, &c.," by Thomas Tredgold, 4th Ed., 1842.

determining the constant c being then insufficient. Mr. Hodgkinson's formulæ, (*q. v.*,) derived from his own extensive experiments afterwards met with universal approbation for a time. The confessed *inconveniences* of Hodgkinson's formulæ led to the revival of Tredgold's. The value of the constant c was calculated by Mr. Lewis Gordon, from Hodgkinson's experiments, and is now known as "Gordon's formula." It evidently rests *now* on as good experimental evidence as Hodgkinson's own formulæ, and is now generally adopted by the profession.

A theoretical proof *of the form* of the formula will be given in the Chapter on Deflection. The formula is introduced here to make this Chapter complete: it is sufficient to note at present that the term $c\left(\frac{l}{d}\right)^2$ is that introduced by the liability to flexure of a "Long" or "Very Long" Pillar, also that the Strength evidently *decreases* as the ratio $l \div d$ *increases.*

The rule given for the value of d (*see* Notation, Art. 504) being taken as *the least* width of the least simple figure (triangle, rectangle, square) that can be drawn round the cross-section A is only approximate, but is generally *sufficiently accurate.*

[For important cases, d should be taken as the *least* radius of gyration of the cross-section about its centre of gravity.

The formula requires *slight modification* for this purpose, viz., for $\left(\frac{l}{d}\right)^2$ write $\frac{l^2}{12\,r^2}$. The modified formula is given in Rankine's Civil Engineering, Arts. 365 and 366, together with a table of the values of the least radii of gyration for fourteen common forms of cross-section.]

521. Application of Gordon's formula.—Its advantages are—

(1). In consequence of its *form* having been theoretically established, it does not present the discontinuity of Hodgkinson's and Rondelet's formulæ, nor is it limited in its application to the particular forms of cross-section experimented on; in fact its range of application is very great, viz., to "Long," and "Very Long" Pillars, (and even to "Short" Pillars, for when the ratio $l \div d$ is small, the formula merges into that for "Short Pillars," viz., $P = f_c \cdot A$), and *of almost any form of cross-section.*

(2). It is easy of application compared to Hodgkinson's formulæ, as it requires only a table of squares for its rapid use, especially when P or W are the quantities sought.

(3). It has the disadvantage when A is the quantity sought (the most useful problem) that, if A be *definitely* expressible in terms of d (as is usual in simple cross-sections, *e. g.*, squares, circles, &c.) a quadratic with *inconvenient* numerical co-efficients results for determining d. Still this can always be solved (*see* Ex. 3, 4, 5, Art. 533.)

If however A be not *definitely* expressible in terms of d, (as is the case in any cross-section but the simplest,) *e. g.*, in rectangles an additional term b is involved, and especially in wrought-iron work in which two additional terms b and t are usually involved,) the problem is indeterminate, *i. e.*, there are more unknown quantities, (viz., b, d ; or b, d, t) than equations, and it may require several trials before a satisfactory solution can be obtained. There being then more unknown quantities than equations, either some relations must be *assumed* between them, or the values of some of them must be provisionally *assumed* such as experience dictates. The most convenient method is that which avoids the difficulty of solving the quadratic, (if many such calculations have to be performed, this is a practical hint of importance), by first *assuming* the value of d to be some quantity as experience dictates; if there be still two unknown quantities, viz., b and t, one of them can be assumed at pleasure (noting that b cannot be $< d$ by hypothesis). On solving the equation two defects may arise.

(*a*). If t has been the quantity assumed, b may result $< d$, which would make the formula inapplicable.

(*b*). If b has been the quantity assumed, t may turn out to be a thickness too great, or toosmall for practical convenience. In either case the formula must be tried again with different assumptions: a few trials will give a satisfactory result. (*See* Ex. 6 for practical exemplification).

522. Best Form of Pillar.—It has been explained that it is possible to utilize the full power of resistance to "direct crushing" of the whole of the material *only* in the case of a "Short Pillar," and that the Strength of a Pillar decreases as the ratio $l \div d$ increases. Economy of material, and therefore *usually* the best form of Pillar, are attained by arranging the material so that d *may have the greatest value* for a Pillar of given length l, that practical considerations admit of, and that, if possible, the Pillar may be a "Short Pillar." Obviously, therefore, a solid Pillar is *theoretically* wasteful of material. Referring to the safe limits of working load intensity given in Art. 504, it is seen that *Solid Pillars* of one

inch square in their least section, will carry Working Loads uniformly distributed as follows :—

Timber, ..	.. ..	$W = 1000$ lbs.,	if l not $>$ 10 inches.
Cast-iron, ..	.. ..	$W = 10$ tons,	if l not $>$ 5 inches.
Wrought-iron,	.. ..	$W = 5\frac{1}{2}$ tons,	if l not $>$ 10 inches.

It has been already explained that of solid "Pillars" of equal area the Square is the strongest form of rectangle, also that the Ultimate Strengths of the following simple solid cross-sections *of equal area* are approximately as,

Circle : Square : Equilateral Triangle $= 10 : 9{\cdot}3 : 11$......(14)

The best forms of complex, and hollow cross-sections will be considered separately for each material, as considerations of cost of, and facility of, construction greatly modify the forms suited to different materials, *e. g.*,

(1). Solid cross-sections are economical in Stone, Brick and Timber.

(2). Hollow cross-sections are economical in metals, viz., of curved outline in cast metal, and of flat outlines with sharp angles, in rolled metals.

It has also been explained that it is possible to utilize the full power of resistance to "direct crushing" of the whole of the material, only when the Load is uniformly distributed over the area of *every* cross-section. It follows that economy of material is secured by making "Pillars" of uniform cross-section.

Further it has been shown that economy of material is secured in the case of "Long" and "Very Long Pillars" by firmly fixing the ends.

It appears then that *economy of material* is in general secured,

(1). By adjusting the joints or points of application of the Load, so that the stress may be uniformly distributed.

(2). By making "Pillars" of uniform cross-section.

(3). In "Long" or "Very Long Pillars" by firmly fixing the ends.

(4). By so arranging the form of cross-section that the Pillar may if possible, be a "Short Pillar".

523. Materials.—The materials usually subjected to crushing strain are—

(1) In Building: Stone, Brick, Cement, Concrete, Mortar; Cast-iron, Wrought-iron; Timber.

(2) In Manufactures: Cast Metals; Wrought-iron; Steel.

The following is an epitome of their principal properties with reference to *crushing* strain.

524. Stone, Brick, Cement, Concrete.—These all resist crushing stress well and other stresses badly, and are in consequence seldom used except to sustain crushing stress. Their properties are fully described under Building Materials. It may be here noted.

(1). Laminated stones resist pressure perpendicular to their laminæ better than in other directions, and should therefore generally be set with their laminæ or quarry beds perpendicular to the line of pressure, (*i.e.*, usually horizontal). The values of f_c tabulated, are for this direction.

(2). Of stones of one kind, the heaviest is generally the strongest.

(3). The strongest stones are Basalts, Primary Limestones, and Slates. Sandstones vary *greatly* in strength according to their molecular structure.

(4). The hardest stones and some sandstones, alone give way to crushing *suddenly*.

Other Stones and also Bricks, begin to crack and split under a load *varying from ½ of the crushing load upwards. Stone generally yields by shearing.* (*See* Class II. "Mode of Failure," Art. 509, (*b*)).

(5). Experiments on the Strength of stone have hitherto been *generally* made on cubes, (*i.e.*, "Very Short Pillars,") so that the tabulated values of f_c are generally *too high*. Experiments on "Short Pillars" (*q. v.*) are desirable. For *important* structures the best course is not to trust to books, but to ascertain the value of f_c for the stone chosen by direct experiment on "Short Pillars."

(6). The division of a column into horizontal courses *each of which is a monolith*, well dressed and bedded does not sensibly* diminish its resistance *to crushing, but vertical jointing does diminish that resistance.*

(7). In consequence of the expense of cutting, solid sections are the only *economical* ones: the actual Crushing Strength of these materials is seldom worked up to: architectural and economical considerations generally fix the outline of "Pillars" of these materials.

525. Cast-iron.

(1). Its resistance to "direct crushing" is very high and is about 6 times its tenacity in consequence of its crystalline structure: (*i.e.*, $f_c = 6 f_t$), so that it is well suited to resist "direct crushing" stress, *i. e.*, for use as a "Short Pillar." (Compare Art. 509).

* Morin, "Résistance des Matériaux," page 28.

(2). But its Resistance to bending is small, because its Modulus of Elasticity (E_t) is comparatively low, so that it is not well suited for use as a "Long" or "Very Long" Pillar.

(3). Remelting improves its strength, *e. g.*, 18 meltings have been found (by Mr. Fairbairn) to double* the strength.

(4). Intense cold makes it brittle: rapid changes of temperature cause it to split sometimes.

(5). Thin castings have a higher resistance to "direct crushing" per unit of area than thick.

(6). The surface of thin castings is stronger than the heart: in thick castings the Strength does not sensibly vary.

(7). A slight inequality in thickness of hollow Pillars does not impair their Strength much.

(8). The "best form" for Cast-Iron Pillars appears to be that of a *hollow circular cylinder:* the thickness is seldom made less than $\frac{1}{12}$ of the diameter,† *i. e.*, t, not $< \frac{1}{12} d$.

(9). Cross and Channel Cast-iron "Pillars" are weak: for the best form of *solid* section, *see* equation (14).

526. Wrought-iron.

(1). Its tenacity is very high, and is about $1\frac{1}{2}$ times its resistance to "direct crushing," *i. e.*, $f_t =$ about $\frac{3}{2} f_c$. It is well suited to resist "direct crushing," *i. e*, for use as a "Short Pillar."

(2). In consequence of its tenacity and resistance to "direct crushing" being both high, it resists flexure well, and is well suited for use as a "Long" or "Very Long" Pillar.

(3). "Long" Tubular Pillars of *square* section (consisting of four equal plate irons riveted to equal angle irons at the corners) fail, when l not $> 15\ d$ to $20\ d$, and t not $< \frac{d}{30}$ by "buckling," *not by crushing*, under a Breaking Load of

27,000 lbs. or 12 tons *per square inch of iron* if single.
36,000 lbs. or 16 tons " " side by side.
"Long" Tubular Pillars of *circular* section 36,000 lbs.

The Resistance to "buckling" *increases* with the ratio $\frac{t}{d}$, but no formula has been given.

* Rankine's "Civil Engineering," 6th Ed., Art 333.
† Rankine's "Civil Engineering," 6th Ed., Art. 363.

(4). The *stiffest* form of "Long Pillar" is that of *a cell, i. e.*, a built tube which may be cylindric, rectangular, or triangular.

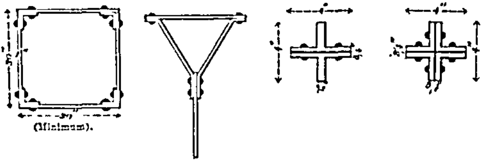
There are practical difficulties in the way of making up small cylindric tubes; the figures show a built rectangular cell, *Fig.* 8 *(a)*, and a triangular cell *Fig.* 8 *(b)* suited for the compression flange, (*see* Chapter on Transverse Strain) of a Girder. Small cells, *i. e.*, cells of small area, present practical inconveniences in the impossibility of painting their interior surfaces properly originally, so as to protect them from exposure, and of obtaining access to them afterwards to examine the state of their interiors.

A cell should be at least big enough to admit of passage of a boy to work inside, *i. e.*, at least 30 inches wide and high.

A very convenient form of cross-section is that of a built up St. Andrew's Cross. Thus it may be built of two T-irons, or of four angle-irons riveted back to back, or of flat plates (two or more) united by four angle-irons, (*see Fig.* 8, (*c*), (*d*), (*e*).

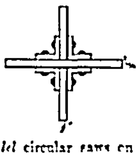
Fig. 8.

(*a*). (*b*). (*c*). (*d*).



(Minimum).

(*e*).



(5). To insure the *stiffness* of a built pillar or strut, the bars of which it is built should break joint when in several lengths. (The compression flange of a girder is a good example of such a case).

The abutting of successive lengths against each other should be equable, and perpendicular to the lengths: to insure this, every bar should have clean plane ends: this is best arranged by a pair of *parallel* circular saws on a common axis, set at a distance equal to intended length of bar: a bar placed parallel to the axis of the saws, and moved against them has its two ends cut at once into parallel planes, perpendicular to its length.

(6). In consequence of the difficulty of fastening the ends of *single* angle-irons, and *single* T-irons, otherwise than by riveting the angle-irons by one arm, and the T-irons by the head, in which case the Resultant of the Stress clearly lies at the greatest possible distance from the axis of the Pillar, and therefore produces the greatest possible amount of flexure, single angle-irons, and single T-irons are quite unsuited for use as "Pillars," and *especially* as "Long" or "Very Long Pillars." From experiments made at the Crumlin Works, it appears that the reduction in strength of some of the following forms of rolled iron due to riveting by *one* flange only is very great, as may be seen from the following Table*:—

Shape.	Size.	Breaking Weight in Tons		Remarks.
		Load uniform over cross-section	Load applied at one flange.	
Angle-irons, ..	$3'' \times 3'' \times \frac{5}{16}''$	$18\frac{3}{4}$	$12\frac{1}{4}$	
T-iron, ..	$3'' \times 3'' \times \frac{3}{8}''$	$21\frac{1}{4}$	$18\frac{1}{4}$	*N.B.*—Lengths not mentioned.
Channel-iron, ..	$3'' \times 1\frac{3}{4}'' \times \frac{3}{8}''$	17·1	14·1	
Cross iron, ..	$3'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$	17·1	15·6	

It will be observed that the reduction in strength is greatest in the angle irons, as might have been anticipated.

Although the use of angle-irons riveted in this manner is evidently very *unfavorable to economy of material*, nevertheless it may often happen that, in consequence of the comparative cheapness of angle-iron, and the great ease (and therefore cheapness) of riveting by only one arm, it will be *the cheapest mode available.* Whenever its cheapness renders its use *in this manner* advisable, the great reduction of strength must be remembered in designing the area of metal necessary.

Unfortunately *no formula*, accurate or approximate, is extant for this purpose: an accurate formula would probably be more complex than formula (4), *q. v.* (in which the *bending* action of the load is introduced), as both *Bending* and *Twisting* actions occur in angle-iron loaded as proposed.

The extremely unfavorable mode of applying the load, viz., by riveting by only one flange, may however often be avoided, even when angle-irons

* Unwin's Lectures in 1871 "On the Construction of Wrought-iron Bridges," Chatham.

and T-irons are used as "Pillars," by using them in pairs, placing them *one on each side* of the bar from which the crushing stress is to be transferred to them, and fixing them at that distance apart throughout their length by "filling-pieces" at intervals. Although the Stress cannot be said to be uniformly distributed by this arrangement, the Resultant Stress is brought to more nearly co-incide with the axis of figure of the compound Strut, so that the *Bending* and *Twisting* actions on the compound Strut are nearly got rid of. Instances of this arrangement will be given in the Bracing of Iron Roofs. (*See* Ex. 8, Chapter XXV.)

527. TIMBER.—In consequence of variations in the molecular structure, the Strength is different in different directions.

(1). The Strength is much *greatest in the direction of the fibres*, so that Timber subjected to crushing strain, should whenever possible, be set so that the Stress may be parallel to the fibres.

(2). Resistance to crushing depends to a great extent on the lateral adhesion of the fibres. Moisture in the timber reduces this lateral adhesion, and *reduces* thereby the crushing strength to *one-half* of that of dry timber.

(3). The Crushing Strength of dry timber varies from $\frac{1}{2}$ to $\frac{2}{3}$ of its tenacity, *i. e.*, $f_c = \frac{1}{2} \cdot f_t$ to $\frac{2}{3} f_t$.

(4). The recorded values of f_c are, when not otherwise stated, to be always understood as referring to the Crushing Strength of dry timber parallel to the fibres.

(5). Crushing *across* the grain takes place by a sort of shearing or sliding; experiments on timber loaded in this manner show that it is *not nearly* so favorable a manner of loading: no definite laws have been discovered.

(6). In consequence of the expense of cutting wood, *solid* sections are in practice the only *economical* sections for timber, (*see* Art. 522).

528. Strength of Timber Piles.—Piles are generally loaded by a pressure *in the direction of their length*, and are therefore "Pillars," and their *Strength* is to be estimated according to the principles of this Chapter, with the following modifications:—

(1). *Piles driven till they reach firm ground.* The imbedded and projecting portions should be separately considered.

(*a*). *The imbedded portion.*—This receives so much lateral support from the ground into which it is driven, that it is not liable to flexure,

and its Strength may be fairly estimated as for a "Short Pillar" (disregarding the *length* imbedded).

(*b*). *The projecting portion.*—This portion should be treated as a Pillar *fixed at one end* only.

Working Load.—The factor of safety may be taken as 5, but the Strength of wet timber being $= \frac{1}{2}$ Strength of dry timber, there results,

Intensity of Working Load for Piles driven to firm ground, and wholly imbedded, or nearly so, $= \frac{1}{2} f_c \div s = f_c \div 10 = 1000$ lbs. *per* square inch on the average.

(2). *Piles standing in soft ground by friction.*—It is impossible to utilize the full powers of resistance of such piles to "direct crushing". Their safe Working Load depends *chiefly on the Resistance of the soil*, and not on their *Strength*.

Working Load Intensity, from practical examples. { (Rondelet's Rule)* = 427 to 498 lbs. per square inch. (Rankine's Rule)† = 200 lbs. per square inch.

In any case (1) or (2) it is considered advisable that the least breadth of a Pile should not be less than 1-20th of the length, to enable them to take up the blows of the ram used in driving without undue flexure.

(3). For the theory of Pile-driving, *see* Chapter XXIV., Art. 555.

529. Crushing and Collapsing of Tubes under normal pressure.

(1). *Thin cylinders.*—When a *thin* hollow cylinder or tube is pressed *normally* from without, it gives way by "collapsing" under a pressure whose law is expressed as follows‡ for circular sections.

Intensity of Ultimate Resistance to collapsing $q \propto t^{2.19} \div ld$, or

$$= ft^{2.19} \div ld = ft^2 \div ld \text{ (approximately)} \quad \text{.......................(19)}$$

Here $l =$ length of tube, or length between its strengthening bands.

For plate iron flues with butt joints $f = 9{,}672{,}000$ lbs.

For an elliptic section ($2a$, $2b$, the axes), for d in above formulæ, substitute twice the radius of curvature where the tube is weakest, *i. e.*, flattest in curvature, *i. e.*, write $\frac{2a^2}{b}$ for d.

N.B.—These rules are derived from experiment, and are only approximate.

(2).—*Thick cylinders.*—When a thick hollow cylinder is pressed normally from without, (*e. g.*, as by fluid pressure), there is a circumferential thrust round it whose greatest intensity takes place at the *inner* surface.

* Morin "Résistance des Matériaux," page 71.

† Rankine's "Manual of Civil Engineering," 6th Ed., Art. 402.

‡ Fairbairn's "Useful Information for Engineers," 2nd Series.

Let R, r be the external and internal radii (in inches) of the cylinder (supposed circular).—

q = intensity (in pounds per square inch) of the normal pressure *from without*, that will *crush* the cylinder.

= ultimate normal intensity of pressure.

q' = intensity (in pounds per square inch) of the normal pressure *from within*.

Then * $(f_c + q - q').\,R^2 = (f_c - q')\,r^2$..............................(20).

In designing a tube it should be made strong enough to resist the external pressure even if not partially relieved by the internal, hence taking $q' = o$, it follows that

$$\frac{r}{R} = \sqrt{1 - \frac{2q}{f_c}} \text{ and } \frac{r}{R} = \sqrt{1 - \frac{2q \div s}{f_c \div s}} \quad \text{..............} \quad (21).$$

These equations give the ratio $\frac{r}{R}$ of internal to external radius of a *thick* tube, that will just give way by "direct crushing" at the *inner* surface under an external normal pressure of intensity q, or will safely bear a Working normal pressure of intensity $q \div s$, and are found to give satisfactory results for thick cylinders.

They are applicable to water pipes laid under water or deep in the soil.

530. Weight of Pillar itself.—The Weight of the Pillar itself, *when it forms a part of the whole crushing Load* on the Pillar, (which will always be the case when the Pillar is not horizontal,) should in strictness be included in the gross Load, whether Breaking, Proof, or Working. It is, however, important to notice, that unless the Pillar be of great length, its own Weight will often *in practice* (especially in Timber and Iron work) in Engineering be so small a fraction of the whole Load, that it may be neglected.

The only *ordinary* case in which it becomes necessary (in practice) to consider the weight of the Pillar itself, is in *lofty* masonry structures, especially Towers and Piers.

531. Pillar of "Uniform Strength."—A Pillar of uniform strength under *direct* compression alone, (*i. e.*, not liable to bending), should be designed (*mutatis mutandis*, *i. e.*, changing f_t to f_c, &c,) on the principles in Art. 498, *q. v.* It is, however, hardly ever necessary in *practical* Engineer-

* Rankine's Applied Mechanics, Art. 287.

ing to design Pillars of "Uniform Strength." Professor Rankine has recently suggested the advisability of designing *very lofty* masonry dams, so as to be of Uniform Strength, but as these dams are necessarily subject to severe Transverse Strain, their consideration is deferred, (*see* also Art. 449).

PRACTICAL SOLUTION OF PROBLEMS ON COMPRESSION.

532. The Problems which occur in practice are of two kinds—

(1). DIRECT.—*Given* A, l, d, f_c, s, *to find* P *and* W.

(2). INDIRECT —*Given* P *or* W, f_c, s, l, *to find* A *and* d.

533. THE DIRECT PROBLEM.—*Given* A, l, d, f_c, s, *to find* P *and* W.

The solution of this problem is comparatively simple.

(1*st*). Consider the value of the ratio $l \div d$ which determines the class of Pillar, viz., "Very Short," "Short," "Long," or "Very Long," (*see* Art. 503).

(2*nd*). If of Class III. or IV., consider the state of fixation of the ends which has an important influence on the Strength (*see* Art. 511). It is a matter of choice which formula (Hodgkinson's, Rondelet's, or Gordon's) shall be adopted, (Art. 510).

(3*rd*). Consider the distribution of the load, as unequal distribution has an important influence on the Strength (*see* Arts. 501 and 507 *(b)*).

The application of these principles is so simple, that no numerical examples seem necessary.

534. THE INDIRECT PROBLEM.—*Given* P *or* W, l, f_c, s *and the form of cross section, to find* A *and* l.

This is by far the *most useful* problem, but it is also the most *difficult*. The difficulty consists in the ratio $l \div d$ which determines the Class of Pillar not being known *à priori*.

(1). Express, if possible, A in terms of d: this can often be done in simple forms of cross section as in wood-work, and sometimes in iron-work. Consider the distribution of the load—Apply formulæ (2) or (4) for "Short Pillars" according as the load is uniformly or unequally distributed. If the value of d resulting make the ratio $l \div d$ fall within the limits for "Short Pillars," the solution is correct, but *not otherwise*.

(2). If from the last trial it appears that the Pillar falls under Class III. or IV.; consider the state of fixation of the ends. There is now a choice between three formulæ (Hodgkinson's, Rondelet's, and Gordon's).

(*a*). *Rondelet's* is the most easily applied (applicable only to simple

cross-sections in timber), but as k must be assumed by guess work, it may have to be several times applied before a correct result can be obtained (*see* Art. 519, and Ex. 3).

(*b*). *Hodgkinson's* suits well enough for *solid* Pillars of uniform rectangular, circular, or triangular section (*see* hints on its application, Arts. 513 and 518, and Ex. 4, 5).

(*c*). *Gordon's*, is the only one applicable to *any* cross section, so that in wrought-iron work in which complex cross-sections are used to economise material it is very useful (*see* hints on its application, Art. 521).

533. Here follow six Examples worked out to illustrate the application of the formulæ in this Chapter.

Example 1.—Working Load (W) $=$ 12,000 lbs. $= 5\frac{5}{14}$ tons, *uniformly distributed.* Find *the least breadth (d)* of Solid "Short Pillar" required, and also the limit of length as a "Short Pillar" in the following cases:—

(1), Square Teak Pillar; (2), Round Cast-iron Pillar; (3), Round Wrought-iron Pillar.

Solution:—$\mathrm{A} = \mathrm{P} \div f_c = s\mathrm{W} \div f_c$, or $\mathrm{A} = \dfrac{\mathrm{W}}{2240} \div s_c$.

(1). *Square Teak Pillar.*—$f_c = 12000$, $s = 10$, $d^2 = \mathrm{A}$.

$\therefore d = \sqrt{\mathrm{A}} = \sqrt{s\mathrm{W} \div f_c} = \sqrt{10 \times 12000 \div 12000} = \sqrt{10} = 3\frac{1}{3}$ inches.

Also limit of Length as "Short Pillar" is l not $> 10d$, *i. e.*, not $> 33\frac{1}{3}$ inches.

(2). *Round Cast-iron Pillar.*—$f_c = 112{,}000$, $s = 5$, $s_c = 10$, $\frac{\pi}{4}d^2 = \mathrm{A}$.

$$\therefore d = \sqrt{\frac{4}{\pi}.\mathrm{A}} = \sqrt{\frac{4}{\pi}s\mathrm{W} \div f_c} = \sqrt{\frac{4}{\pi}.5 \times 12{,}000 \div 112{,}000} = \sqrt{\frac{15}{7\pi}} = \cdot 83 \text{ in.}$$

$$\text{or thus, } d = \sqrt{\frac{4}{\pi}\mathrm{A}} = \sqrt{\frac{4}{\pi}.\frac{\mathrm{W}}{2240} \div s_c} = \sqrt{\frac{4}{\pi} \times \frac{75}{7} \div 10} = \sqrt{\frac{15}{7\pi}} = \cdot 83 \text{ inches.}$$

Also Limit of Length as "Short Pillar" is l not $> 5d$, *i. e.*, not $> 4{\cdot}2$ inches.

(3). *Round Wrought-iron Pillar.*—$f_c = 40{,}000$, $s = 4$, $s_c = 5\frac{1}{2}$, $\frac{\pi}{4}d^2 = \mathrm{A}$.

$$\therefore d = \sqrt{\frac{4}{\pi}.\mathrm{A}} = \sqrt{\frac{4}{\pi}.s\mathrm{W} \div f_c} = \sqrt{\frac{4}{\pi}.\frac{4 \times 12000}{40000}} = \sqrt{\frac{24}{5\pi}} = 1\tfrac{1}{4} \text{ inches.}$$

$$\text{or thus, } d = \sqrt{\frac{4}{\pi}.\mathrm{A}} = \sqrt{\frac{4}{\pi}.\frac{\mathrm{W}}{2240} \div s_c} = \sqrt{\frac{4}{\pi}.\frac{75}{14} \div 5{\cdot}5} = \frac{10}{11}\sqrt{\frac{3}{2}} = 1\tfrac{1}{8} \text{ in.}$$

Also Limit of Length as "Short Pillar" is l not $> 10d$, *i. e.*, not > 12 inches.

Remark.—It will now be evident that it is *practically* convenient to

use the co-efficient $f_c \div s$ or s_c according as W is expressed in pounds or tons.

Example 2.—Working load (W) = 12000 lbs = $5\frac{5}{14}$ tons, distributed so that its resultant deviates $\frac{1}{6}$-th of least breadth from the centre of figure of the least section (*i. e.*, $x_o = d \div 6$) along that least breadth. Find *the least breadth* (d) of "Short Pillar" required, and also the limit of length as a "Short Pillar" in the following cases:—

(1), Square Teak Pillar; (2), Round Cast-iron Pillar; (3), Round Wrought-iron Pillar.

Solution :—$\text{A} = \text{P} \cdot \left(1 + x_o \cdot \frac{x_1 \text{A}}{\text{I}}\right) \div f_c = s\text{W} \cdot \left(1 + x_o \cdot \frac{x_1 \text{A}}{\text{I}}\right) \div f_c$.

Also in square pillars $\frac{x_1 \text{A}}{\text{I}} = \frac{6}{d}$, $d^2 = \text{A}$.

And in round pillars $\frac{x_1 \text{A}}{\text{I}} = \frac{8}{d}$, $\frac{\pi}{4} d^2 = \text{A}$.

(1). *Square Teak Pillar.*—$f_c = 12000$, $s = 10$.

$$\therefore d = \sqrt{s\text{W}\left(1 + \frac{d}{6} \cdot \frac{6}{d}\right) \div f_c} = \sqrt{2\, s\text{W} \div f_c} = \sqrt{20} = 4\tfrac{1}{2} \text{ inches.}$$

Also Limit of length as "Short Pillar" is l not > $10d$, *i. e.*, not > 45 inches.

(2). *Round Cast-iron Pillar.*—$f_c = 112000$, $s = 5$.

$$\therefore d = \sqrt{\frac{4}{\pi} \cdot s\text{W} \cdot \left(1 + \frac{d}{6} \cdot \frac{8}{d}\right) \div f_c} = \sqrt{\frac{7}{3} \cdot \frac{4}{\pi}\, s\text{W} \div f_c} = \sqrt{\frac{5}{\pi}} = 1\tfrac{1}{4} \text{ inches.}$$

Also Limit of Length as "Short Pillar" is l not > $5d$ *i. e.*, not > $6\frac{1}{4}$ inches.

(3). *Round Wrought-iron Pillars.*—$f_c = 40000$, $s = 4$.

$$\therefore d = \sqrt{\frac{4}{\pi}\, s\text{W} \cdot \left(1 + \frac{d}{6} \frac{8}{d}\right) \div f_c} = \sqrt{\frac{7}{3} \frac{4}{\pi}\, s\text{W} \div f_c} = \sqrt{\frac{7 \times 8}{5\pi}} = 1.9 \text{ in.}$$

Also Limit of Length as "Short Pillar" is l not > $10d$, *i. e.*, not > 19 inches.

Remark.—The effect of unequal distribution of the load in *diminishing* the Strength of the Pillar, and thereby necessitating a greater sectional area (A), *to bear the same Working Load will be evident from comparing* Examples 1 and 2.

The solutions just given are of course applicable only to "Short Pillars," *i. e.*, when $l \div d$ does not exceed the limits mentioned.

The following examples will illustrate the difficulties of application of the formulæ for "Long" and "Very Long" Pillars.

Example 3.—Working Load (W) = 12,000 lbs. = $5\frac{5}{14}$ tons uni-

formly distributed. Find *the least breadth (d)* of a Solid Square Teak Pillar of length (L) = 16 feet *fixed at both ends* required.

Solution :—It will be found (by actual trial, *see* Example 1), that this Pillar is not a "Short Pillar," so that the formula for "Long" and "Very Long" Pillars must be used. *N.B.*—The constant C of Hodgkinson's Formula not having been determined for Indian Woods, his formula cannot now be used. $f_c = 12000$, $s = 10$.

By Rondelet's formula.—$A = P \div (k \,.\, f_c) = sW \div (k \,.\, f_c)$, $d^2 = A$.

The ratio $l \div d$, on which k depends, not being known *à priori*, the value of k must be assigned *by guess work.* The limit of length for a "Short" Pillar being (*see* Example 1), about 33 inches, the ratio $l \div d$ is evidently *large* in the present case.

Assume $k = \frac{1}{3}$ *provisionally.* Then

$$l = \sqrt{A} = \sqrt{sW \div (kf_c)} = \sqrt{10 \times 12000 \div (\tfrac{1}{3} \times 12000)} = \sqrt{30} = 5\tfrac{1}{2} \text{ inches.}$$

Hence $l \div d = 12\,L \div d = 192 \div 5{\cdot}5 = 35$: the value of k corresponding to this is $\frac{1}{3}$ (*see* Table), the value chosen, so that the solution is correct. But this accordance might not have been attained without several trials.

$$\textit{By Gordon's formula.}\text{—}sW = P = f_c \,.\, A \div \left\{1 \times c \,.\left(\frac{l}{d}\right)^2\right\}, c = \frac{1}{250}, A = d^2$$

$$\therefore 10 \times 12000 \times \left\{1 + \frac{1}{250} \times \frac{(12 \times 16)^2}{d^2}\right\} = 12000\, d^2,$$

$$d^4 - 10d^2 = 192^2 \div 25 = 1474{\cdot}56, \text{ whence } d = 6{\cdot}6 \text{ inches.}$$

Remark.—The quadratic presented in this case is easier of solution than would commonly occur. The *discrepancy* between the result and that given by Rondelet's formula should be noticed. It is probably due to the uncertainty (alluded to in Art. 519) in using Rondelet's formula, which contains no factor depending on the state of "fixation of the ends." Gordon's formula is, on account of its greater precision, to be preferred.

Example 4.—Working Load (W) = 12000 lbs. = $5\frac{5}{14}$ tons *uniformly distributed.* Find *the least breadth (d)* of Solid Round Cast-iron Pillar of length (L) = 16 feet, *fixed at both ends.*

Solution :—It will be found (by actual trial, *see* Ex. 1), that this Pillar is not a "Short Pillar," so that the formulæ for "Very Long Pillars" must be tried. $f_c = 12000$, $s = 5$.

By Hodgkinson's formula for "Very Long Pillars."—(Eq. (10), Art. 516).

$$d^{3\cdot6} = \frac{P}{2240} \,.\, \frac{L^{1\cdot7}}{44{\cdot}16} = \frac{sW}{2240} \,.\, \frac{L^{1\cdot7}}{44{\cdot}16} = 5 \times \frac{75}{14}\, \frac{16^{1\cdot7}}{44{\cdot}16} = \frac{375 \times 16^{1\cdot7}}{618{\cdot}24}$$

Hence $d = 3\frac{1}{4}$ inches. As $l \div d = 12\,L \div d > 30$, the Pillar is a "Very Long Pillar," and the solution is correct.

By Gordon's formula.—$sW = P = f_c A \div \left\{1 + c \cdot \left(\frac{l}{d}\right)^2\right\}$, $c = \frac{3}{800}$, $A = \frac{\pi}{4} d^2$

$$\therefore 5 \times 12000 \times \left\{1 + \frac{3}{800} \cdot \frac{(16 \times 12)^2}{d^2}\right\} = 112000 \times \frac{\pi}{4} d^2$$

$$15 \left\{d^2 + 138\cdot24\right\} = 22\, d^4, \text{ whence } d^4 - \frac{15}{22} d^2 = \frac{15}{22} \times 138\cdot24$$

$$\therefore d^2 = \frac{15}{44} \sqrt{812}, \text{ whence } d = 3\tfrac{1}{10} \text{ inches.}$$

Example 5.—Working Load (W) = 12,000 lbs. = $5\frac{5}{14}$ tons *uniformly distributed.* Find *the least breadth* (d) of Solid Square Wrought-iron Pillar of length (L) = 16 feet, *free at both ends.*

Solution :—It will be found (by actual trial, *See* Ex. 1) that this Pillar is not a "Short Pillar," so that the formula for "Very Long Pillars," must be tried. $f_c = 40000$, $s = 4$.

By Hodgkinson's formula for "Very Long Pillars" (Eq (12), Art. 516).

$$d^{3\cdot76} = \frac{P}{2240} \cdot \frac{L^2}{42\cdot8} \text{ for } \textit{round} \text{ pillars.}$$

But the Strengths (P) of *Circular* and *Square* Pillars *of same breadth* (d) are as 1 : 1·6 (*Equation* 15).

$$\therefore d^{3\cdot76} = \frac{1}{1\cdot6} \cdot \frac{P}{2240} \cdot \frac{L^2}{42\cdot8} \text{ for square pillars.}$$

$$= \frac{1}{1\cdot6} \cdot \frac{sW}{2240} \cdot \frac{L^2}{42\cdot8} = \frac{4 \times 75}{1\cdot6 \times 14} \times \frac{16^2}{42\cdot8} = 80$$

whence $d = 3\frac{1}{4}$ inches. As $l \div d = 12\,L \div d = 60$, the pillar is a "Very Long Pillar," and the solution is correct.

By Gordon's formula.—$sW = P = f_c A \div \left\{1 + c \cdot \left(\frac{l}{d}\right)^2\right\}$, $c = \frac{1}{3000}$, $A = d^2$.

$$\therefore 4 \times 12000 \left\{1 + \frac{1}{3000} \cdot \frac{(12 \times 16)^2}{d^2}\right\} = 40000\, d^2$$

$$d^4 - \cdot6 d^2 = 7\cdot3728, \text{ whence } d^2 = \cdot3 \pm \sqrt{7\cdot4628}. \text{ Hence } d = 3 \text{ inches.}$$

Example 6.—Working Load (W) = 1200 lbs = $\frac{15}{28}$ tons *uniformly distributed.* Find the size of Angle-Iron requisite as a Pillar of length (L) = 16 feet *fixed at both ends.*

[illegible]

Hence $A = 2bt$, and $d = b \div \sqrt{2}$ nearly (being *see* Notation, the least breadth of circumscribing triangle). Assume (3) a *provisional* value for b, (*e. g.*, $b = 2$ inches)

Then $A = 2bt = 4t$, and $d = b \div \sqrt{2} = \sqrt{2}$.

Also $l \div d = 12L \div d > 100$, the Pillar is a "Very Long Pillar." Hodgkinson's rmula cannot be used as it contains no factor to suit it to an angle-iron section. ordon's formula alone can be used. The object of assigning a *provisional* value to b stead of to t was (*see* Art. 521), that d might be *provisionally* fixed, and the equation r solution (Gordon's formula), which would be quadratic in d, thus reduced to a *mple* equation in t (a material saving in calculation)

By Gordon's formulæ.—$sW = P = f_c A. \div \left\{1 + c.\left(\frac{l}{d}\right)^2\right\}$, $c = \frac{1}{3000}$, $d^2 = 2$.

$$\therefore 4 \times 1200 \times \left\{1 + \frac{1}{3000}.\frac{(12 \times 16)^2}{2}\right\} = 40000 \times 4t$$

$$\therefore t = \frac{3}{100} \times \left\{1 + \frac{36864}{6000}\right\} = \cdot 214 \text{ inches, or say } \tfrac{1}{4} \text{ inch.}$$

Remark.—As the resulting size, viz., $2'' \times 2'' \times \frac{1}{4}''$ is an ordinary size f Angle Iron, the solution is a *practical* one: but this result might not ave been attained without several trials (*see* Art. 521), *e.g.*, t might have rned out either so *great* or so *small* that practical considerations would ender such a solution useless: in such a case, a fresh *provisional* value ust be assigned to b, and the formula tried again.

The term "provisional value" will now be understood as meaning a alue to be considered dependent on the solution being satisfactory as r as *practical* considerations are concerned.

[*N.B.*—Further Examples of application of Gordon's formula to T-iron and ⅃L-(double angle-) iron sections will be found at end of Ex. 8, Chapter XXV.]

ADDENDUM TO CHAPTERS XXII. AND XXIII.

TENSION AND COMPRESSION.

534. A fitting sequel to the Chapters in which the states of Tension and Compression are considered separately in detail, will be to compare and contrast them. The following is a brief statement of results from Chapters XXII. and XXIII:—

(1). The LOAD, STRAIN, RESISTANCE, STRESS are *direct* in action, *i. e.*, normal to the surfaces of particles in mutual contact, and mutually parallel to one another.

(2). A state of Tension is one of stable equilibrium; a state of Compression is one of unstable equilibrium.

(3). Resistance to Tension is a comparatively simple, and Resistance to Crushing a comparatively complex phenomenon.

(4). The laws of Resistance to *uniformly distributed* Load or Stress are in both cases expressible by the same algebraic formula—

$$P = f_t \cdot A \text{ or } P = f_c \cdot A \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

(provided the material under crushing strain be of class termed a "Short Pillar" in Chapter III., *q. v.*).

(5). The full powers of Resistance *of the whole* of the material under strain cannot be utilized in either case, unless the Load or Stress be uniformly distributed.

Cor.—Material should if possible be so arranged, that the Load or Stress may be approximately uniformly distributed over its cross-sectional area.

(6). Material under crushing strain in form of a "Long Pillar" is liable to additional strain from flexure, and the Strength of "Long Pillars" decreases rapidly with the increase of the ratio $l : d$ (length to least breadth of cross section).

(7). Unequal distribution of Load or Stress is *extremely* disadvantageous in material exposed to crushing.

(8). Fibrous and Ductile Materials are best suited to resist Tensile Strain. (*Example.*—Wrought-iron, Rolled and Drawn-metals, Cordage, Timber).

Crystalline, Semi-Crystalline and non-Fibrous Materials are best suited resist "direct" Crushing Strain. (*Example.*—Cast-iron, Stone, Brick) form of "Short Pillars."

Wrought-iron is best suited to resist crushing complicated by bending in "Long Pillars."

(9). Timber resists Stretching better than Crushing, and resists both parallel to its fibres much better than across; its Strength (especially Crushing Strength) is much reduced by moisture.

535. Combination of Cast-iron and Wrought-iron.—As Cast-iron resists "direct" crushing strain in "Short Pillars" much better than Wrought-iron, and as Wrought-iron resists tensile strain much better than Cast-iron, as may be seen by comparing the values of the constants (Arts. 481 and 504) for each,

$$\left.\begin{array}{llll} \text{Cast-iron,} & \dots\ s_t = 1\tfrac{1}{2}\ \text{tons}; & s_c = 10\ \text{tons} \\ \text{Wrought-iron,} & \dots\ s_t = 7\ \text{tons}; & s_c = 5{\cdot}5\ \text{tons} \end{array}\right\}\ \text{per square inch.}$$

It might be supposed that in a Structure exposed in parts to Tensile, in parts to Crushing, Strains, a combination of Cast and Wrought-iron would be most economical, viz., by the use of Cast-iron to resist the "direct" Crushing Stresses, and of Wrought-iron to resist the Tensile Stresses.

Such a combination has been frequently tried, but has been found very efective in consequence of the contraction in the Cast-iron being much greater than the simultaneous elongation in the Wrought-iron as may be seen by comparing their Moduli of Elasticity, thus (*see* Chapter XXIV).

Cast-iron, $E_c = 17$ million lbs.; Wrought-iron, $E_t = 29$ million lbs.,

that the Cast-iron portions, by their greater yielding, suffer an undue tion of the Load to fall on the Wrought-iron, from which it commonly ppens that the Wrought-iron is strained beyond its elastic limit (*see* rts. 538 and 539) long before the full power of Resistance of the Cast-on has been called out. This has been amply proved by the experiments f Mr. W. Fairbairn.*

* Fairbairn's "Application of Cast and Wrought-iron to Building Purposes," 1861.

CHAPTER XXIV.

STIFFNESS, ELASTICITY, SET.

536. **Stiffness or Rigidity.**—*Rigidity* or *Stiffness* is the property of a solid body of resisting *Strain* (or alteration of figure), which the action of load tends to produce. It may be measured *by the ratio* of intensity of Stress of a particular kind to the intensity of Strain produced.

Pliability is the property of a solid body of yielding to strain: it is therefore converse to Stiffness, and may be measured by the reciprocal of the measure or Modulus of Stiffness.

Thus Modulus of Stiffness = Stress-intensity ÷ Strain-intensity ...(1).

Modulus of Pliability = Strain-intensity ÷ Stress-intensity ...(2).

It is a remarkable thing that in most Building Materials the value of this ratio is approximately constant *within the limits of the proof stress.*

No bodies in nature are *perfectly* rigid, *i. e.*, able to bear Load without any strain or alteration of figure, but many Building Materials are approximately rigid *under small loads, i. e.*, yield insensibly, *e.g.*, Hard Stone, and Hard Brick.

No *solid* bodies in nature are *perfectly* pliable: most *liquids* approximate to perfect *lateral* pliability, and most *gases* when not near their point of liquefaction approximate to perfect pliability.

537. **Elasticity** is the property of recovery of figure when the stres (causing the *strain* or alteration of figure) ceases.

Set is the permanent residual strain, or alteration of figure, after cessation of the stress or straining force.

Elasticity is said to be "perfect" or "imperfect" according as the re-covery of figure after the cessation of the stress is complete or incomplet, *i. e.*, according as there is no Set or Set.

No solid body has quite "perfect" *Elasticity*, *i. e.*, a slight Set is pro-duced by the action of any Load however small.

[This has been ascertained by the experiments of Mr. Hodgkinson and Prof. W. Thomson: it may also be inferred from the principle of "Conservation of Energy," (Art. 475,) from which it appears that, in consequence of some of the "Work" done by a Load in straining any material being converted into Heat, which is lost by radiation and conduction under all ordinary circumstances, a portion of the energy *communicated* to the material is *in general* "dissipated," so that on the removal of the Load the remaining (*i. e.*, Potential) Energy of the material is not quite sufficient to completely restore its figure].

Nevertheless the Elasticity of many solid bodies (*including* Building Materials) is approximately perfect within the limits of the Proof Stress, and is "sensibly perfect" *practically within the limits of any Stress* (not exceeding the proof stress) *which has been previously applied* and produced its set. This result (of experiment) is very important in Engineering, and should receive the careful attention of the Student.

538. Limit of Elasticity.—The limit of Strain or Stress within which elasticity is "sensibly perfect" is called the Elastic Limit or "Limit of Elasticity." This limit is important because experience shows that the resistance of materials to stress or strain *exceeding* that limit is *irregular* and not easily calculable, and that their Strength is *permanently impaired* by such Stress or Strain.

539. Working Stress or Strain.—It is, therefore, an accepted dictum in Engineering that the Proof Stress and Strain should not exceed the elastic limit, and *à fortiori* the "Working Stress and Strain must invariably be confined within that limit."

540. Co-efficients of Elasticity.—It has been proved, by Green, that there are 21 independent co-efficients of elasticity of an elastic heterogeneous solid strained in any manner: in a *perfectly homogeneous* ("isotropic") solid, these reduce to two, viz.:—

(1). *Co-efficient of Direct Elasticity, i. e.*, of Resistance to Direct Longitudinal Stress (viz., Extension and Compression).

(2) *Co-efficient of Transverse Elasticity, i. e.*, of Resistance to Tangential Stress (viz., Shearing or Distortion).

Building Materials, though not "isotropic," are *practically* sufficiently approximately homogeneous to admit of consideration of these two co-efficients only: the former is by far the more important in Engineering.

541. Hooke's Law and Modulus of Elasticity.—The *Modulus* (*i. e.*, Measure) *of Elasticity* of any kind is the value of the Measure of Stiffness (Eq. (1), Art. 536) of that kind *within the elastic limit, i. e.*,

when the elasticity is *sensibly perfect.* It is found *by experiment* that *within this limit* this quantity is *sensibly constant* for Building Materials: it is usually denoted by E. Hence

"Modulus of Elasticity" = "Stress-intensity ÷ Strain intensity"
= E ....(3).

(*N.B*—E is a *Constant* quantity for each stress, *e. g*, stretching, crushing, transverse, shearing, &c, for each Material)

Result (3) may be expressed in this form, "Stress ∝ Strain", or "Stress "is proportional to Strain" (*within the elastic limit*): this was originally expressed "ut tensio sic vis", and is known as "Hooke's Law of Elasticity."

N.B—It is particularly to be observed that this law is approximately true for Building Materials, *only within the 'elastic limit'*, i. e, it is true only as a "first approximation," still it is very remarkable that it should be really a *good* approximation for most Building Materials* for *all* kinds of load application, (i. e, Direct or Transverse) up to the limit of Strain or Stress by which their Strength is *permanently* injured (Art. 538).

The simplicity of this law, viz, "Stress ∝ Strain" has a most important bearing on Applied Mechanics: indeed the modern treatment of Applied Mechanics, *i. e.*, Engineering calculation (especially in the Higher Branches) depends *entirely on this law.* This must be carefully borne in mind by the Student.

542. *Notation.*—In this Treatise the Modulus of Elasticity of a particular kind will be denoted by E with a subscript letter indicating the kind of stress, thus:—

E_t = Modulus of direct tensile elasticity.

E_c = Modulus of direct compressive elasticity.

E_d = Co-efficient of deflexional elasticity under Transverse Load.

E_s = Modulus of Transverse (tangential, *i. e.*, shearing) elasticity.

p = Intensity of stress of a given kind (in pounds per square inch).

l = Length of a piece of *unstrained* material (in inches.)

λ = Longitudinal strain, *i. e.*, contraction or elongation of l under the stress.

ν = Measure of *distortion*, *i. e*, Shearing Strain-intensity (Art. 465).
= Cotan. of angle of distorted prism, square when unstrained.

σ = Set produced by longitudinal stress of intensity p.

* Cast-iron seems to form a remarkable exception to this Law, see Art. 544.

543. *Tensile and Compressive Elasticity* (E_t *and* E_c).—Tension and Compression being both "direct" in action, *i. e.* (*see* Chapters II. and III.), producing strains parallel to the external applied forces (or loads), the algebraic expression of Hooke's Law, Eq. (3), is the same for both.

Thus λ being the *Total strain* or alteration of length l, it follows that

$$\left.\begin{array}{l}\text{"Strain-intensity"} = \lambda \div l \text{ in each case,} \\ \quad \textit{i. e.}\text{, whether elongation or contraction,}\end{array}\right\} \ldots\ldots\ldots\ldots\ (4).$$

$$\left.\begin{array}{l}\text{hence from Eq. (3), } \dfrac{\text{Stress-intensity}}{\text{Strain-intensity}} = \dfrac{p}{\lambda \div l} = \\ = \text{a constant for the material} = \text{"Modulus of Elasticity,"} \\ \quad \therefore \dfrac{p}{\lambda \div l} \text{ or } \dfrac{p}{\lambda} \,.\, l = E_t\text{, or } E_c \text{ (as the case may be),}\end{array}\right\} \ldots\ldots\ldots\ldots (5).$$

i. e., according as p is a tensile or compressive stress, *provided it be within the elastic limit.*

544. Equation (5) furnishes the following remarkable physical interpretation of the meaning of E_t and E_c, viz.,

$$E_t \text{ or } E_c = p, \text{ if } \lambda = l \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6).$$

i. e., the Modulus of direct longitudinal elasticity (whether tensile or *compressive*), viz, E_t *or* E_c, *is the stress-intensity*, *i. e.*, p, *or the number* of pounds per square inch (*see* Art. 468,) of area under direct stress, which will produce a total strain, (elongation or contraction,) viz., λ *equal in amount* to the original length (l) of the material (under the *imaginary* hypothesis that the limit of elasticity is not exceeded).

Although a strain $\lambda = l$, could not be produced in any Building Material without exceeding the elastic limit (beyond which Hooke's Law fails), so that the physical interpretation of E_t and E_c, as given, is quite *imaginary as applied to Building Materials*, still the interpretation is useful, if only as furnishing a conception of a physical meaning to these co-efficients.

It will be seen that E_t and E_c are quantities of the same order as p, *i. e.*, not *actual* weights but only *intensities* of weight (viz., pounds per square inch).

545. *Values of* E_t and E_c *approximately equal* in Building Materials. *It is a remarkable thing, and attended with important consequences in* Engineering, that most Building Materials are so nearly "isotropic," (Art. 540) for Stresses *within the elastic limit*, that the values of λ, viz., the elongation or contraction in l under stretching or crushing stress *of the same intensity* p are nearly equal, so that the values of E_t and E_c are for most Building Materials approximately equal. This point should receive

careful attention, as it will be found (in subsequent Chapters) that the Mathematical treatment of "Transverse Strain" and "Deflexion," depends entirely on the assumption that $E_t = E_c$.

546. *Transverse Elasticity* (E_s).—The Modulus E_s of Transverse (Shearing) Elasticity is not of much *practical* use, still its consideration is necessary to complete the subject, and to illustrate Hooke's Law.

Consider the state of a *square* prism of the material with Shearing (Tangential) Stresses applied to its four faces.

As by definition (Art. 468 and 512),

p = Shearing Stress-intensity (in pounds per sq in.) over the faces of the prism.

ν = Measure of *distortion*, *i. e.* Shearing Strain-intensity.

Then by Eq (3), provided the Strain or Stress be confined within the elastic limit,

$$\left.\begin{array}{l}\dfrac{\text{Stress-intensity}}{\text{Strain-intensity}} = \dfrac{p}{\nu} = \text{a constant for the material, } \ldots\ldots \\ \quad = \text{“ Modulus of Transverse Elasticity ”} = E_s, \ldots\ldots\end{array}\right\}(7).$$

It is a remarkable fact that the measure (ν) of the *distortion* of the prism is equal to the *sum* of the intensities of strain produced in the diagonals of the prism, thus :—

If d = Length of diagonal of an unstrained square prism.

δ = Total strain (elongation $= \delta_t$, contraction $= \delta_c$) of its diagonals.

Then $\nu = (\delta_t + \delta_c) \div d, \ldots\ldots$ (8).

547. *Determination of the values of* E_t *and* E_c.—There are two methods of doing this—

(1). The "direct" method, *i.e.*, by experiments on *direct* tension and compression.

(2). The "indirect" method, *i. e.*, by experiments on *deflexion* under Transverse Load.

(1). *The "direct" method.*—This is theoretically by far the best method, as no hypotheses are necessary, and the values of E_t and E_c are at once deduced from the fundamental equation (5), viz., E_t or $E_c = p \cdot \frac{l}{\lambda}$ by direct measurement of λ (the elongation or contraction in l) under the action of Direct Stretching or Crushing Load of known intensity p, the Load being of course confined *within the elastic limit*, which is known by the value of $p \cdot \frac{l}{\lambda}$ remaining sensibly constant.

In the experiments on contraction, care must be taken that the "Pillars" experimented on are of such length as to be of the Class styled "Short Pillars" in the Chapter on Compression (Art. 507), as the only ones in which *simple* "direct" crushing takes place. Also, in the experiments on both extension and contraction, care must be taken that the Load

is *uniformly distributed* over the area of the cross section, so that the intensity of the Load may be at once deducible as $p = W \div A$ (Load in pounds $\div$ area of cross-section in inches), and that its action may be *simply* Direct Stretching or Direct Crushing (without the complication of any bending action (*see* Chapters XXII. and XXIII.).

Also it is advisable that the material experimented on should be of uniform or *gradually* changing cross-section throughout its length, to avoid complication of *unequal* lateral strains.

N.B.—Similar precautions are necessary in determining by experiment the moduli f_t and f_c of tenacity and crushing.

A *practical* objection to the "direct" method is that the Load (W) required to produce any sensible strain λ is *very great* indeed, and that within the elastic limit that quantity is in most Building Materials so small as to require great care in its measurement. The great Loads required are *difficult* of application especially in experiments on Contraction in which, for reasons explained in Chapter XXIII. (Art. 501) it is difficult to avoid the complication of a Bending action.

For these reasons the "direct" method is both inconvenient and expensive.

(2). *The indirect method.*—It will be shown (in the Chapter on Deflection) that the maximum deflection δ in a *Solid straight horizontal Beam of uniform rectangular section freely supported* on two supports at the same level, and loaded with a weight (W) *evenly spread across the beam at the middle* of its length (l) is $\delta = \frac{Wl^3}{4 E_t . bd^3}$

Hence $E_t = \frac{Wl^3}{4 bd^3 \delta}$ (For Notation, *see* Arts. 542 and 461) ....(9), so that E_t can be determined by experiments on Deflexion of Beams by measuring the maximum deflexion δ produced by a known Load (W) in a given Beam *such as above*, care being taken that the stress *never exceeds* the elastic limit. (For the discussion of the stresses in this Class of Experiment, see the Chapter on Transverse Strain).

The theoretical objection to this method is that the truth of Equation (9) depends on the *assumption* (*see* the Chapter on Transverse Strain) that $E_t = E_c$. The practical advantages of this method are very considerable. The experiment is *comparatively easy* and inexpensive: the weights required to produce an easily measurable deflexion are compara-

ively small. For these reasons many of the experiments for determination of E_t have been confined to this method.

548. *Hodgkinson's Formulæ.*—Mr. Hodgkinson has given formulæ for the amount of elongation λ_t, and contraction λ_c in the length l, and also for the amount of tensile set σ_t and compressile set σ_c in the same length l in both Cast-iron, and Wrought-iron, *previously unstrained*, deduced from his own extensive experiments.*

(1). *Cast-iron*—

$$\left.\begin{aligned}
\lambda_t &= l\left\{ \cdot 00239628 - \sqrt{\cdot 00000574215 - \cdot 000000000343946\,p} \right\} \\
\lambda_c &= l\left\{ \cdot 012363359 - \sqrt{\cdot 000152853 - \cdot 00000000191212\,p} \right\} \\
\sigma_t &= \cdot 0193\,\lambda + \cdot 64\,\lambda^2 \\
\sigma_c &= \cdot 543\,\lambda^2 + \cdot 0013
\end{aligned}\right\} \quad (10)$$

Mr. Hodgkinson records his opinion that when the compressive stress-intensity $p > 14$ tons per square inch, the contraction λ_c is *irregular*, and that when $p < 2$ tons per square inch, the contractions are *insensible*, so that experiments for determining E_c in Cast-iron should be within these limits. These formulæ are remarkable, as being quite different *in form* from Equation (5) whence $\lambda = \frac{p}{E} \cdot l$, and throwing therefore a doubt on the *practical* applicability of Hooke's Law† to Cast-iron. A considerable difference is also observable in the values of λ_t and λ_c for the same stress-intensity p, making it doubtful whether in Cast-iron E_t, E_c are sufficiently nearly equal to permit disregarding the difference.

These results do not appear to have received sufficient attention in the profession, as Cast-iron structures are still designed as if Hooke's Law and the result $E_t = E_c$ were strictly applicable.

(2). *Wrought-iron*—

Peter Barlow's result,‡ $\lambda_t = \cdot 000096\,l\,p$ very approxly. when $p < 10$ tons per sq inch
Hodgkinson's results,* $\lambda_t = \cdot 00008\,l \cdot p$ very approxly. when $p < 12$ tons per sq inch
$\lambda_c = \cdot 0001\,l \cdot p$ very approxly. when $p < 12$ tons per sq inch (11).

When $p > 12$ tons or 12×2240 lbs. per square inch, rapid and irregular stretching takes place under tension, and irregular bulging under pressure.

* "Report of Commissioners on the application of Iron to Railway Structures, 1849," pages 64, 109, 123, 59, 60, 108.

† Compare Art. 441.

‡ Barlow's "Strength of Materials," Ed. 1845, p. 313.

These results agree with Hooke's Law of Elasticity, and with Equation (5) $\lambda = \frac{pl}{E}$, and it is also seen that $\lambda_t = \lambda_c$ *nearly*, and therefore $E_t = E_c$ *nearly*, so that there appears to be no objection to employing these two important equations to Wrought-iron structures.

549. Co-efficient of deflexional elasticity.—It was shown on theoretical grounds by Peter Barlow* that, in a Solid straight horizontal Beam of uniform rectangular section freely supported on two supports at the same level, and loaded with a weight (W) evenly spread across the beam at the middle of its length l, the following quantity, $\frac{Wl^3}{bd^3\delta}$ is a *constant quantity* for any one material provided certain limits of Load (corresponding to the elastic limit) be not exceeded. This quantity he terms "the Elasticity," and proposes to use it as a *measure* of the Elasticity under Deflexion: he denotes it by E: in this Treatise it will be denoted by E_d, the subscript d being intended to indicate that it is derived from experiments on Deflexion.

It is particularly to be noticed that this quantity E_d does not fulfil the Definition of the term "Modulus of Elasticity" (given by Rankine) as used in this Treatise, *see* equation (3); it is *defined* solely by the fundamental equation,

$$\frac{Wl^3}{bd^3\delta} = E_d, \text{ a \textit{constant} within certain limits of Load} \;\ldots\ldots\ldots\ldots (12).$$

It is, however, certainly a "measure" of Elasticity under Deflexion, and has therefore been styled (Art. 542) in this Treatise the "Co-efficient" of "Deflexional Elasticity."

Barlow's investigation of the fundamental Equation (12) involves only the assumption of Hooke's Law of Elasticity; its truth was also established by himself *by experiment* on Deflexion of Beams such as above. It might be supposed therefore that Equations (5) and (12), viz., $p \cdot \frac{l}{\lambda} =$ constant, and $\frac{Wl^3}{bd^3\delta} =$ constant, although both are algebraic expressions of the same physical law, viz., Hooke's Law of Elasticity, yet being algebraic expressions of this Law under very different applications, viz., Eq. (5) under Direct Stress, Eq. (12) under Transverse (Bending) Load, there would be no necessary physical connection between them, much less any simple numerical relation between E_t or E_c the constants derived from Equation (5), and E_d the constant derived from Equation (12).

* Barlow's "Strength of Materials," Ed. 1845.

On making, however, the additional assumption that $E_t = E_c$ (not re-quired in Barlow's investigation), equation (9), *q. v.*, viz., $E_t = \frac{Wl^3}{4\,bd^3\,\delta}$ is deduced. Comparing with equation (12) it follows that

$$E_d = 4\,E_t \quad \text{(13)}$$

so that E_d is now seen to be a co-efficient not expressing any different physical relations to E_t or E_c (on the assumption that $E_t = E_c$), and *differing from it by only a numerical co-efficient.*

550. Various tabulated Modifications of E_d.—Since the quantity $\frac{Wl^3}{bd^3\,\delta}$ has been shown to be constant, Eq. (12), within the elastic limit for any one material under certain conditions, it follows that $k \times \frac{Wl^3}{bd^3\,\delta}$ is a constant quantity under the same conditions if k is simply a numerical co-efficient.

Unfortunately experimentalists and compilers of tables have chosen *different numerical co-efficients* k in calculating the co-efficient of their tables, so that the quantity tabulated as the "co-efficient of Deflexion Elasticity" (*i. e.*, E_d) *differs* in different tables according to the value chosen by the tabulator for k. In using any Tables of E_d, *great care* is requisite to ascertain the exact formula from which the E_d was calculated, *i. e.*, to determine the value of k.

The principal *tabulated* modifications of E_d are given below, together with their relation to the E_d employed in this Treatise, styled "the Roorkee E_d," and also to E_t, and a list of some of the works, including Indian ones, in which they occur. As it is very undesirable to increase the number of these modifications (each modification being simply a source of embarassment to the Engineer), and as the "Roorkee E_d" is already *largely employed in India*, it is strongly recommended to future tabulators of experiments on Indian materials to use only the "Roorkee" E_d, (even though they may be of opinion that it is not the best form of co-efficient,) as uniformity of tables saves much work of computation.

Various tabulated modifications of E_d.

(1). $E_d = \frac{l^3 W}{bd^3\,\delta} = 1728 \times \text{Roorkee } E_d = 4\,E_t$, ... (12) and (13).

"Essay on Strength and Stress of Timber," by P. Barlow, 3rd Edition, 1826.
"Treatise on Strength of Timber, &c.," by P. Barlow, New Edition, 1845, Art. 61.
"Gleanings of Science," Vol. I., May and August, (Experiments by Capt. H. C. Baker), Calcutta 1829.

On making, however, the additional assumption that $E_t = E_c$ (not required in Barlow's investigation), equation (9), *q. v.*, viz., $E_t = \frac{Wl^3}{4\,bd^3\,\delta}$ is deduced. Comparing with equation (12) it follows that

$$E_d = 4\ E_t \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13).$$

so that E_d is now seen to be a co-efficient not expressing any different physical relations to E_t or E_c (on the assumption that $E_t = E_c$), and *differing from it by only a numerical co-efficient.*

550. Various tabulated Modifications of E_d.—Since the quantity $\frac{Wl^3}{bd^3\,\delta}$ has been shown to be constant, Eq. (12), within the elastic limit for any one material under certain conditions, it follows that $k \times \frac{Wl^3}{bd^3\,\delta}$ is a constant quantity under the same conditions if k is simply a numerical co-efficient.

Unfortunately experimentalists and compilers of tables have chosen *different numerical co-efficients* k in calculating the co-efficient of their tables, so that the quantity tabulated as the "co-efficient of Deflexion Elasticity" (*i. e.*, E_d) *differs* in different tables according to the value chosen by the tabulator for k. In using any Tables of E_d, *great care* is requisite to ascertain the exact formula from which the E_d was calculated, *i. e.*, to determine the value of k.

The principal *tabulated* modifications of E_d are given below, together with their relation to the E_d employed in this Treatise, styled "the Roorkee E_d," and also to E_t, and a list of some of the works, including Indian ones, in which they occur. As it is very undesirable to increase the number of these modifications (each modification being simply a source of embarassment to the Engineer), and as the "Roorkee E_d" is already *largely employed in India*, it is strongly recommended to future tabulators of experiments on Indian materials to use only the "Roorkee" E_d, (even though they may be of opinion that it is not the best form of co-efficient,) as uniformity of tables saves much work of computation.

Various tabulated modifications of E_d.

(1). $E_d = \frac{l^3 W}{bd^3\,\delta} = 1728 \times \text{Roorkee } E_d = 4\ E_t, \ldots\ldots (12)$ and (13).

"Essay on Strength and Stress of Timber," by P. Barlow, 3rd Edition, 1826.
"Treatise on Strength of Timber, &c.," by P. Barlow, New Edition, 1845, Art. 61.
"Gleanings of Science," Vol. I, May and August, (Experiments by Capt. H. C. Baker), Calcutta 1829.

acceptance under the influence of T. Tredgold the great authority on Carpentry and Iron-work: *this practice is, however, obviously most unsatisfactory* for the following reasons :—

(*a*). Wind is usually *observed* to blow *horizontally*, and can hardly be conceived as blowing *vertically* downwards.

(*b*). Wind being simply *current air* follows the laws of *fluids in motion*, *i. e.*, of hydrodynamics; its pressure (as ascertained by experiment) on any given surface does not admit of being resolved in any chosen direction (vertically for instance) according to the simple laws of Statics of Rigid Bodies.

(*c*.) Its pressure moreover (being a fluid) is *normal* to a surface pressed, and not *vertical* as under Tredgold's supposition.

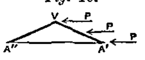
(*d*). Wind can hardly be conceived as pressing *on both sides of a roof at the same time*.

Now all the four absurdities (*a*), (*b*), (*c*), (*d*), just noticed are involved in the application of Tredgold's method: the only possible advantage obtained by Tredgold's mode of estimation of Wind-pressure as a "uniformly distributed vertical pressure" is that the whole of the Loads over the Roof, both Permanent and Accidental are thus assumed to be *of one character*, viz., "uniform vertical pressures," so that their intensities may therefore be added thereby yielding *in one sum* the Total Load-intensity over the whole Roof, so that the Total or Resultant Stresses may thus be found by *one* operation.

This certainly simplifies calculation, but the practice cannot be thereby defended *if incorrect in fact*. It might be supposed with reference to (*d*) that a Truss designed (as by Tredgold's method) to stand a Wind-pressure of the given maximum-intensity, *on both sides at the same time*, errs on the side of strength, *i. e.*, *of safety*, but this is by no means the case, for it will appear below, that a Load applied *on one side only* of Roof has a totally different straining effect on certain bars to *the same Load* applied *to both sides at once*.

This is sufficiently obvious from the following simple Example :—

Fig. 10.



Horizontal pressures P applied *to one side only* as A'V of the triangular frame or truss A'VA' would produce Pressure in the bar A'V, and Tension in the bar A'V.

Equal opposite horizontal pressures applied over the bar A'V only would produce Tension in the bar A''V, and Pressure in the bar A'V equal in magnitude to the Pressure and Tension respectively in the former case.

The whole system of pressures *applied simultaneously* would actually balance each other as far as the bars A'V, A'V are concerned, and leave these bars unstrained,* whereas if the frame be liable to either system of pressures *separately*, the bars A'V, A'V must be capable of sustaining *both* Tension and Pressure alternately.

It appears (from observation) that the most violent winds that usually occur exert† *a horizontal pressure* of 40 lbs. per square foot *of a vertical surface*, but in consequence of Wind being simply *current air*, its pressure on any surface is essentially *normal to the surface*, and reduced in the following ratio, *derived from the experiments* of Hutton—

w' = intensity of *horizontal* wind-pressure in lbs. per square foot of *vertical* surface.

= about 40 lbs. as a maximum (in England, and as far as records exist in India also).

w'_n = intensity of wind-pressure on any surface inclined at an angle $= i$ to the wind's direction, *i. e.*, of slope i.

$$= w \,.\, (\sin i)^{(1\cdot 84 \cos i - 1)} \quad \ldots\ldots \quad (1).$$

Note that the pressure w' is a *hydrodynamical* pressure, whereas the pressure w'_n is equivalent to a simple *statical* pressure, and admits therefore of being resolved in any direction by the rules of Statics (of rigid bodies), thus:—

$$\left.\begin{array}{l}\text{The horizontal component of } w'_n = w'_n \cos(90^\circ - i) = w \,.\, (\sin i)^{1\cdot 84 \cos i} \\ \text{The vertical component of } w'_n = w'_n \sin(90^\circ - i) = w \cot i \,.\, (\sin i)^{1\cdot 84 \cos i}.\end{array}\right\} (2).$$

As the quantity w'_n and its horizontal and vertical components when required in calculation are difficult of reduction, the following Table is subjoined for reference, taking $w' = 40$.

Slope i in degrees.	INTENSITIES IN POUNDS PER SQUARE FOOT.			Remarks.
	Normal Pressure.	Components of Normal Pressure.		
		Horizontal.	Vertical.	
5	5	4·9	·4	
10	9·7	9·6	1·7	
20	18·1	17	6·2	
30	26·4	22·8	13·2	
40	33·3	25·5	21·4	
50	38·1	24·5	29·2	
60	40	20	34·0	
70	41	14	38·5	
80	40·4	7	39·8	
90	40	0	40	

* There being no Transverse Strain under the hypothesis of "Rigidity," Art. 563.

† Unwin's "Wrought-iron Bridges and Roofs," Art. 164.

cceptance under the influence of T. Tredgold the great authority on Carentry and Iron-work: this practice is, however, obviously most unsatisactory for the following reasons :—

(*a*). Wind is usually *observed* to blow *horizontally*, and can hardly be conceived as blowing *vertically* downwards.

(*b*). Wind being simply *current air* follows the laws of *fluids in motion*, *i. e.*, of hydrodynamics; its pressure (as ascertained by experiment) on any given surface does not admit of being resolved in any chosen direction (vertically for instance) according to the simple laws of Statics of Rigid Bodies.

(*c*.) Its pressure moreover (being a fluid) is *normal* to a surface pressed, *and not vertical as under Tredgold's supposition.*

(*d*). Wind can hardly be conceived as pressing *on both sides of a roof at the same time.*

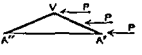
Now all the four absurdities (*a*), (*b*), (*c*), (*d*), just noticed are involved n the application of Tredgold's method: the only possible advantage btained by Tredgold's mode of estimation of Wind-pressure as a "uniormly distributed vertical pressure" is that the whole of the Loads over he Roof, both Permanent and Accidental are thus assumed to be *of one haracter*, viz., "uniform vertical pressures," so that their intensities nay therefore be added thereby yielding *in one sum* the Total Load-inensity over the whole Roof, so that the Total or Resultant Stresses may hus be found by *one* operation.

This certainly simplifies calculation, but the practice cannot be thereby lefended *if incorrect in fact.* It might be supposed with reference to (*d*) hat a Truss designed (as by Tredgold's method) to stand a Wind-pressure f the given maximum-intensity, *on both sides at the same time*, errs on the ide of strength, *i. e.*, *of safety*, but this is by no means the case, for it will ppear below, that a Load applied *on one side only* of Roof has a totally lifferent straining effect on certain bars to *the same Load* applied *to both ides at once.*

This is sufficiently obvious from the following simple Example:—

Horizontal pressures P applied *to one side only* as A'V f the triangular frame or truss A'VA'' would produce ressure in the bar A'V, and Tension in the bar A'V.

Fig. 10.



Equal opposite horizontal pressures applied over the bar A'V only would produce Tension in the bar A''V, and ressure in the bar A'V equal in magnitude to the Pressure and Tension respectivey in the former case.

CM', $C''M''$ the Queen-rods, vertical, trisecting the Tie-rod in M', M''.

$C'C''$ the Straining-beam, horizontal.

$M'M''$ the Straining-sill, horizontal.

$B'M'$, $B''M''$ the Struts, which with the Straining-beam $C'C''$ trisect the Rafters in B', C', and B'', C'', so that $B'M'$, $B''M''$ are parallel to VA', VA'', respectively.

N.B. See Remarks in Art. 564 as to use of open quadrilateral $C'M'\,M''C''$.

Notation, See Arts. 577 and 578. The Total or Resultant Stresses of the several bars composing the Frame are denoted *in general* by the capital letters attached, and the *partial* Stresses due to the partial Load (at the contiguous joint only) by the corresponding small letters.

Note, that, *in strictness* the weight of the Straining-beam $C'C''$ should be *separately* estimated (as coming on the joints C', C''), but this weight alone is so small compared to unavoidable irregularities in distribution of the Load W (supposed uniform over $A'VA''$, *see* Art. 577) that it does not seem worth while increasing the complexity of the investigation by introducing *separate* consideration of this.

586. Step I. *Load on each joint.*—Under the hypotheses explained (Art. 563), that each Bar is rigid between joints, and perfectly free at the joints, and as the segments of the rafters are all equal, the Load borne by each rafter-segment is $\frac{1}{6}$ of the whole weight of roofing, *i. e.* $=\frac{W}{6}$, also (Eq. 5, Art. 570), each rafter-joint bears $\frac{1}{2}$ of the Load on each contiguous rafter-segment together with any load directly supported: thus

$$\left.\begin{array}{l}\text{Load at V is }\tfrac{1}{2}\text{(Load on VC}'\text{ and}\\ \quad \text{VC}'')+\text{Direct Load w}\end{array}\right\}=\tfrac{1}{2}\left(\frac{W}{6}+\frac{W}{6}\right)+w=\left(\frac{W}{6}+w\right)$$

$$\left.\begin{array}{l}\text{Load at C}'\text{ or C}'',\ \text{B}'\text{ or B}''\text{ is}\\ \tfrac{1}{2}\text{ (Load on two rafter-segments)}\end{array}\right\}=\tfrac{1}{2}\left(\frac{W}{6}+\frac{W}{6}\right)\qquad=\frac{W}{6}$$

$$\left.\begin{array}{l}\text{Load at A}'\text{ or A}''\text{ is}\\ \tfrac{1}{2}\text{(Load on A}'\text{B}'\text{ or A}''\text{ B}'')\end{array}\right\}=\tfrac{1}{2}\cdot\frac{W}{6}\qquad=\frac{W}{12}$$

$$\text{Load at M}'\text{ or M}''\text{ is}\qquad w'$$

Also since the Roof is symmetrical and symmetrically loaded, the Reactions at the supports are each one-half of the Total Load, *i. e.*,

$$\text{Re-action at A}'\text{ or A}''=\tfrac{1}{2}\,(W+w+2w')=\frac{W+w}{2}+w'$$

$$\text{Also Sum of Load at joints}=\left(\frac{W}{6}+w\right)+4\cdot\frac{W}{6}+2\cdot\frac{W}{12}+2w'=$$

$$=(W+w+2\,w')=\text{Total Load,}$$

ıd such a construction is very unfavorable to economy of material, and should only ɔ used for temporary structures which from local necessities may have to be made of ıseasoned wood when wood is plentiful, and good carpentry not obtainable.*

584. *Results of Art.* 582 *collected for reference.*

$$' = S'' = \frac{W}{8} \cdot \operatorname{cosec} i, \text{ (Thrust on Struts),} \dots\dots (1).$$

$$= \frac{W}{4} + w', \text{ (Tension of King-rod),} \dots\dots (2).$$

$$' = T_1'' = \tfrac{1}{2}\left(\frac{W}{2} + w + w'\right) \operatorname{cosec} i, \text{ (Thrust on Rafter top-segments),} (3).$$

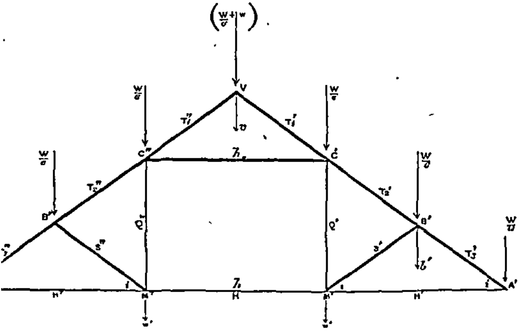
$$' = T_2'' = \left(\frac{3W}{8} + \frac{w + w'}{2}\right) . \operatorname{cosec} i, \text{ (Thrust on Rafter lower segments),} (4).$$

$$I' = H'' = \left(\frac{3W}{8} + \frac{w + w'}{2}\right) . \cot i, \text{ (Tension of Tie-rod),} \dots\dots (5).$$

'ertical Pressure on each Wall $= \frac{1}{2}(W + w + w')$,……………(6).

Ex. 2: *Symmetrical Queen-Post Truss under Symmetric vertical Load.*

Fig. 15.



ı85. *Description.*—A′V′, A″V the Rafters of equal length A′V = L = A″V. V′A″ the Tie-rod, horizontal; A′A″ the span $= 2c$.

* *e.g.*, in Hill-campaigns in India.

C'M', C''M'' the Queen-rods, vertical, trisecting the Tie-rod in M', M''.

C'C'' the Straining-beam, horizontal.

M'M'' the Straining-sill, horizontal.

B'M', B''M'' the Struts, which with the Straining-beam C'C'' trisect the Rafters in B', C', and B'', C'', so that B'M', B''M'' are parallel to VA', VA'', respectively.

N.B. See Remarks in Art. 564 as to use of open quadrilateral C'M' M''C''.

Notation, See Arts. 577 and 578. The Total or Resultant Stresses of the several bars composing the Frame are denoted *in general* by the capital letters attached, and the *partial* Stresses due to the partial Load (on the contiguous joint only) by the corresponding small letters.

Note, that, *in strictness* the weight of the Straining-beam C'C'' should be *separately* estimated (as coming on the joints C', C''), but this weight alone is so small compared to unavoidable irregularities in distribution of the Load W (supposed uniform over A'VA'', *see* Art. 577) that it does not seem worth while increasing the complexity of the investigation by introducing *separate* consideration of this.

586. Step I. *Load on each joint.*—Under the hypotheses explained (Art. 563), that each Bar is rigid between joints, and perfectly free at the joints, and as the segments of the rafters are all equal, the Load borne by each rafter-segment is $\frac{1}{6}$ of the whole weight of roofing, *i. e.* $=\frac{W}{6}$, also (Eq. 5, Art. 570), each rafter-joint bears $\frac{1}{2}$ of the Load on each contiguous rafter-segment together with any load directly supported: thus

$$\left.\begin{array}{l}\text{Load at V is } \tfrac{1}{2}\text{ (Load on VC' and}\\ \text{VC'') + Direct Load w}\end{array}\right\} = \tfrac{1}{2}\left(\frac{W}{6}+\frac{W}{6}\right) + w = \left(\frac{W}{6}+w\right)$$

$$\left.\begin{array}{l}\text{Load at C' or C'', B' or B'' is}\\ \tfrac{1}{2}\text{ (Load on two rafter-segments)}\end{array}\right\} = \tfrac{1}{2}\left(\frac{W}{6}+\frac{W}{6}\right) \qquad = \frac{W}{6}$$

$$\left.\begin{array}{l}\text{Load at A' or A'' is}\\ \tfrac{1}{2}\text{ (Load on A'B' or A'' B'')}\end{array}\right\} = \tfrac{1}{2}\cdot\frac{W}{6} \qquad = \frac{W}{12}$$

$$\text{Load at M' or M'' is} \qquad w'$$

Also since the Roof is symmetrical and symmetrically loaded, the Reactions at the supports are each one-half of the Total Load, *i. e.*,

$$\text{Re-action at A' or A''} = \tfrac{1}{2}(W + w + 2w') = \frac{W + w}{2} + w'$$

$$\text{Also Sum of Load at joints} = \left(\frac{W}{6} + w\right) + 4\cdot\frac{W}{6} + 2\cdot\frac{W}{12} + 2w' =$$

$$= (W + w + 2\,w') = \text{Total Load,}$$

Tension of tie-rod C'C" (of Truss C'VC"),

$$h_1 = T_1' \cos i = T_1'' \cos i = \left(\frac{W}{12}+\frac{w}{2}\right)\cot i \ldots\ldots\ldots\ldots\ldots\ldots\ldots(11\text{-i}),$$

l *also* produce a vertical pressure on the joints C', C" of the lower Truss clearly ıal to their vertically resolved parts, *i. e.*,

Vertical pressure on C', C" (from load on V) $= T_1' \sin i = T_1'' \sin i = \left(\frac{W}{12}+\frac{w}{2}\right)$

). The total Load on the joints C', C" *of the lower Truss* will therefore be $\frac{W}{6}$ (direct d, *see* Step I.) + Q' or Q" (Tension of Queen-rod) + $\left(\frac{W}{12}+\frac{w}{2}\right)$ just shown be transferred from V through the rafters VC', VC" (*in consequence of the upper ss* C'VC" *being a separate and independent truss* from the lower A'C'C"A"), *i. e.*, Total Load on C', C" (joints of lower truss A'C'C"A")

$$= \frac{W}{6} + \left(\frac{W}{12}+w'\right) + \left(\frac{W}{12}+\frac{w}{2}\right) = \left(\frac{W}{3}+\frac{w}{2}+w'\right)$$

so this load may (precisely as in para. 4) be shown to produce Stresses along the ıining-beam and rafters as follows :—

rust along straining-beam (of Truss A'C'C"A"), $h_2 = \left(\frac{W}{3}+\frac{w}{2}+w'\right)\cot i$, (11-ii)

Thrust along rafter C'B' or C"B", viz, T_2' or $T_2'' = \left(\frac{W}{3}+\frac{w}{2}+w'\right)\operatorname{cosec} i$, (13).

N.B.—It should now be noticed that the results (12) and (13) obtained by this thod *agree exactly* with those (12) and (13) obtained in paras. (5) and (6); also ıt the result (11) obtained in para. (4) *v. supra* for the Resultant Thrust ($h_0 = \frac{W}{4}+w'\Big)\cot i$) along C'C" if so framed as to be a piece of both trusses C'VC" l A'C'C"A" is the excess of h_2 the Thrust along C'C" considered as straining-beam the Truss A'C'C"A" over h_1, the Tension along C'C" considered as tie-rod of the ıss C'VC"; for see Results (11-ii) and (11-i)

$$-h_1 = \left(\frac{W}{3}+\frac{w}{2}+w'\right)\cot i - \left(\frac{W}{12}+\frac{w}{2}\right)\cot i = \left(\frac{W}{4}+w'\right)\cot i = h_0, (11).$$

Note—This accordance of the results (11), (12), (13) obtained in either manner has ın detailed at length, as Students are apt to confuse and mix the two methods.* the two suppositions, viz. :—

(1). (As adopted in the text) that the bar C'C" is so framed as to act both as straining-beam of the lower truss A'C'C"A", and as tie-rod of the small truss C'VC",

(2). (As adopted in the small-type note) that the truss A'C'C"A" has a straining-beam C'C", and that the small truss C'VC" has a *separate* tie-rod C'C" (not shown in the figure), being thus an independent truss simply placed on the lower,

carefully borne in mind throughout, no dificulty should arise.

The Student is recommended to compare the result obtained by the "Polygonal thod", Ex. 10 of method ii.

* This mistake was made in previous editions both of the "Roorkee Treatise on Civil Engineering in India," and Thomason C. E. College Manual, No. XI., on "Carpentry."

(5). *At joint V.*—The Load $\left(\frac{W}{6} + w\right)$ at V is supported by the two resistances T_1', T_1'' of the bars VC′, VC″, which resistances are clearly both thrusts, because the Load compresses both bars, and are, moreover, *equal*, because the bars are equally inclined to the Load; also the sum of their vertically resolved parts is clearly equal to the Load which they support, thus

$$(T_1'.\cos vVA' + T_1''.\cos vVA'') = 2T_1'\cos vVA' = 2T_1'\sin i = \frac{W}{6} + w$$

$$\therefore T_1' = T_1'' = \left(\frac{W}{12} + \frac{w}{2}\right)\operatorname{cosec} i \quad\ldots\ldots\ldots\ldots\ldots\ldots(12).$$

(6). *Total Stresses along middle and lower rafter-segments.*—The Thrusts T_1', T_1'' along VC′, VC″ are clearly transmitted *unaltered* down the whole length of the rafter segments C′A′ and C″A″, respectively; also the thrusts t_2', t_2'', *see* Eq. (10) along the rafter-segments C′B′, C″B″ are transmitted unaltered down B′A′, B″A″ respectively; thus the whole thrusts down middle and lower rafter-segments become

$$T_2' = T_2'' = t_2' + T_1' = \left(\frac{W}{4} + w'\right)\operatorname{cosec} i + \left(\frac{W}{12} + \frac{w}{2}\right)\operatorname{cosec} i =$$

$$\left(\frac{W}{3} + \frac{w}{2} + w'\right)\operatorname{cosec} i \quad\ldots\ldots\ldots\ldots\ldots\ldots(13).$$

$$T_3' = T_3'' = t_1' + t_2' + T_1' = \frac{W}{12}\operatorname{cosec} i + \left(\frac{W}{4} + w'\right)\operatorname{cosec} i +$$

$$\left(\frac{W}{12} + \frac{w}{2}\right)\operatorname{cosec} i = \left(\frac{5W}{12} + \frac{w}{2} + w'\right)\operatorname{cosec} i \quad\ldots\ldots\ldots\ldots\ldots\ldots(14).$$

(7). *Stress on Tie-Rod* A′A″.—These last total thrusts T_3', T_3'' down the rafter-segments, B′A′, B″A″ produce a horizontal *tensile* Stress H′, H″ on the Tie-rod segments A′M′, A″M″, and a vertical pressure on the walls at A′, A″. The horizontal pulls H′, H″ are clearly equal to the horizontally resolved parts of the thrusts T_3', T_3'' respectively, thus

$$H' = T_3'.\cos i,\quad H'' = T_3''.\cos i.$$

$$\therefore H' = H'' = \left(\frac{5W}{12} + \frac{w}{2} + w'\right).\cot i, \text{ from (14)} \quad\ldots\ldots\ldots (15).$$

N.B.—This equality of the horizontal stresses H′, H″ on the tie-rod segments might have been foreseen, as it is clearly *necessary to the equilibrium* of the whole tie-rod: thus there is a tension throughout the whole tie-rod.

$$H' = H = H'' = \left(\frac{5W}{12} + \frac{w}{2} + w'\right).\cot i, \ldots\ldots\ldots\ldots\ldots (15).$$

This equality affords a check on the investigation.

(8). *Resultant Stress along middle of tie-rod* M'M''.—It has just been explained that there is a *tension* $\mathrm{H} = \left(\frac{5\mathrm{W}}{12} + \frac{\mathrm{W}}{2} + \mathrm{w}'\right) . \cot i$, throughout the tie-rod, and there was shown to be a *Thrust* $h = \frac{\mathrm{W}}{12} \cot i$, (*see* Eq. (8), along the straining-sill M'M'' (due to the struts abutting at its ends). If, however, the feet of the struts *abut in the tie-rod itself*, so that the portion M'M'' receives the thrust of the struts, (the straining sill being in this case dispensed with, as a separate piece,) then that portion M'M'' is relieved of a part of its tension H by the Thrust h from the struts, so that *in this case*,

Resultant tension along middle (M'M'') of tie-rod $= \mathrm{H} - h =$

$$= \left(\frac{\mathrm{W}}{3} + \frac{\mathrm{W}}{2} + \mathrm{w}'\right) . \cot i \qquad (16).$$

Note.—By this manner of framing, the Resultant stress along M'M'' is *less* than when a separate straining-sill is used, so that *a lighter scantling* may be used for this portion of the tie-rod and the whole truss is lightened by the absence of the straining-sill. This is a matter of some importance *in large trusses* (especially in iron-work): in wooden trusses the tie-rods are *in practice* made of much larger scantling than actually required to resist the actual Tensions, so that it is of little importance in woodwork.

(9.) *Vertical Pressure on the Walls.*—The Thrusts T_3', T_3'' down the rafter-segments B'A', B''A'' produce a vertical pressure on the walls at A', A'' clearly equal to their vertically resolved parts, *i. e.* $= \mathrm{T}_3' . \sin i$ $= \mathrm{T}_3'' . \sin i = \left(\frac{5\mathrm{W}}{12} + \frac{\mathrm{W}}{2} + \mathrm{w}\right)$ from (14). These together with $\frac{\mathrm{W}}{12}$ shown in Step I. to be borne directly at A', A'' make up a

$$\text{Total Vertical Load at A', A''} = \left(\frac{5\mathrm{W}}{12} + \frac{\mathrm{W}}{2} + \mathrm{w}'\right) + \frac{\mathrm{W}}{12}$$

$$= \frac{\mathrm{W} + \mathrm{w}'}{2} + \mathrm{w}'$$

$$= \text{Re-action at A' or A'' (see Step I.)} \qquad (17).$$

an equality which is clearly necessary (Art. 571). This last step affords a valuable check (*which should never be neglected*) on the investigation.

588. *Remarks on terms Queen-rod, Tie-rod.*—The same remarks as on the terms King-rod, Tie-rod under the King-post truss, apply to this case (changing the words King and Queen)

589. Results of Art. 587 collected for reference.

$$\mathrm{S}' = \mathrm{S}'' = \frac{\mathrm{W}}{12} \operatorname{cosec} i, \text{ (Thrust on struts)}, \qquad (7).$$

$$h = \frac{W}{12} \cot i, \text{ (Thrust on Straining-sill), } \ldots\ldots\ldots\ldots \text{ (8)}$$

$$Q' = Q'' = \frac{W}{12} + w', \text{ (Tension of Queen-rods), } \ldots\ldots\ldots\ldots \text{(9)}$$

$$h_o = \left(\frac{W}{4} + w'\right) \cot i, \text{ (Resultant Thrust on straining-beam), } \ldots\ldots\ldots\ldots \text{ (11)}$$

$$T_1' = T_1'' = \left(\frac{W}{12} + \frac{w}{2}\right) \operatorname{cosec} i, \text{ (Thrust on Rafter top-segments), } \ldots\ldots\ldots\ldots \text{ (12)}$$

$$T_2' = T_2'' = \left(\frac{W}{3} + \frac{w}{2} + w'\right) \operatorname{cosec} i, \text{ (Thrust on Rafter mid-segments), } \ldots\ldots\ldots\ldots \text{ (13)}$$

$$T_3' = T_3'' = \left(\frac{5W}{12} + \frac{w}{2} + w'\right) \operatorname{cosec} i, \text{ (Thrust on Rafter lower segments), } \ldots\ldots\ldots\ldots \text{ (14)}$$

$$H = H' = H'' = \left(\frac{5W}{12} + \frac{w}{2} + w'\right) \cot i, \text{ (Tension of Main Tie-rod), } \ldots\ldots\ldots\ldots \text{ (15)}$$

$$H - h = \left(\frac{W}{3} + \frac{w}{2} + w'\right) \cot i, \text{ (Resultant tension of Middle of main Tie-rod) } \ldots\ldots\ldots\ldots \text{ (16)}$$

$$\text{Vertical pressure on each wall} = \frac{W + w}{2} + w' \ldots\ldots\ldots\ldots \text{ (17)}$$

METHOD ii, OR "POLYGONAL" METHOD.

590. Polygon of Forces.—This method depends on the continua application of the theorem of the "Polygon of Forces" which, as require for this Method, may be thus stated:—

1°. "If a system of forces is in equilibrium, the set of lines *draw in succession* to represent the forces (*i. e.*, proportional to their magni tudes, and parallel to their directions) will form *a closed polygon*".

2°. *Conversely.* "If a system of forces is in equilibrium, and *a close polygon* be formed by drawing a set of lines *in succession* to represent (*i.e.* parallel to the directions of and proportional to the magnitudes of) *al but two of the forces*, and two additional lines (to close the polygon parallel to the remaining two forces, then *these two closing lines will re present the two remaining forces* (*i. e.*, in magnitude as well as in direction)"

N.B.—It is particularly to be noticed that the last theorem (2°) i

not true for more than two forces omitted, inasmuch as many such polygons could be drawn (as will be easily seen by actual trial), so that the construction of the polygon would be indeterminate. This corresponds with the statement in Art. 576, that the Problem of finding more than two unknown stresses at any one joint is indeterminate.

591. Frame-diagram.—Stress-diagram.—This Theorem is thus applied: It will be remembered (*see* Art. 574) that the method is essentially *a graphic* one. In the first place a skeleton diagram of the Truss should be drawn to scale; this is called the "Frame-diagram". The figure (*reciprocal* to the Frame-diagram), whose construction is about to be explained, will represent the system of external Loads and of Stresses in the bars of the Truss: this is called the "Stress-diagram". The construction of the Stress-diagram consists of two steps corresponding to the two steps previously detailed, Art. 565.

STEP I.—Construction of "Polygon of Loads" representing the "Equivalent Loads at the Joints" of Step I. (Arts. 566 to 572, and 592).

STEP II.—Resolution of Loads at the joints by construction of *closed Polygons* of Loads and Stresses representing the whole system of *forces in equilibrium at each joint in succession.* (Arts. 573, 574, and 593).

592. STEP I. **Polygon of Loads.**—The system of external forces, and therefore the Equivalent Loads at the joints as found in Step I., Art. 566 to 570, *q. v.*, together with the Re-actions of the Supports form a system in equilibrium, and can therefore be represented (Art. 590, Prop. 1°) by a set of lines forming *a closed polygon.*

The first step, then, is to draw a closed polygon representing on any scale the system of external forces, (*i. e.*, a set of lines drawn in succession parallel to their directions and proportional to their magnitudes). This diagram is called the "Polygon of Loads".

N.B.—In actual application to Roof Trusses, the external forces are (*see* Art. 567) commonly a system of "parallel forces," viz., either a system of Vertical Loads, being the weights of the various portions of the Structure, or a system of Pressures (due to Wind, as previously explained) normal to the rafters, *together with* the vertical or normal Re-actions, respectively. The "*Polygon of Loads*" *corresponding to a system of* "Parallel Forces" is clearly simply a pair of *overlapping* straight lines, which in this case may be called the "Load Line".

This will be repeatedly exemplified in the examples which follow: the Student is recommended to refer at once to Step I. of any of these examples to illustrate the method of drawing the "Polygon of Loads".

To indicate distinctly *to the eye* that the pair of overlapping lines which constitute the "Polygon of Loads" for the ordinary case of Loads and Re-actions all vertical, or all normal (to the roofing), are really in the limit a "closed polygon", it will be convenient *in the diagram* to separate the Re-actions *slightly* from the Loads so that the whole system of Loads and Re-actions may form a closed polygon *obvious to the eye* (though it must be distinctly remembered that the Loads and Re-actions are really parallel), *see* any Example following.

593. Step II. Resolution of Loads at the joints.—The second Theorem (Art. 590, 2°) of the "Polygon of Forces" is thus applied:—

A *closed* polygon is to be drawn *upon the "Polygon of Loads"* for each joint *in succession* (commencing from both abutments) representing the whole system of forces (including both external Load, Re-actions at Supports, and Stresses in the Bars of the Truss) in equilibrium at that joint, according to the second Theorem (Art. 590, 2°) of the "Polygon of Forces").

It will be found that the polygon drawn for each joint aids in the construction of the polygon for the following joint, and that the final Stress-diagram consists of the originally drawn "Polygon of Loads", and of a network of lines drawn in succession upon a regular principle, representing upon the same scale as chosen for the "Polygon of Loads", the Total or Resultant Stresses required; and that although the finished Stress-diagram for complicated Roof-Truss may appear a somewhat intricate network of lines, still the principle of construction is remarkably simple and easy of application when once thoroughly understood.

The character of the Stress on each Bar, (*i. e.*, whether Tensile or Compressive,) is indicated *in the simplest manner*, viz., by the *direction* in which the pencil travels in the act of drawing the lines representing the Forces taken *in order* at each joint. Moreover, trigonometrical formulæ for the Stresses are *easily* deduced from the Stress-diagram (even if not drawn to scale).

All this will be better understood from study of the examples which follow, to which the Student is recommended to refer at once, than from any general explanation.

594. Check on the investigation.—One of the advantages of the Stress-diagram is that it necessarily contains *an excellent check on its own accuracy* (if drawn to scale). The check consists of two parts:—

st. The "closed polygon" for the last point but one should in gene- close in such a manner that some of its lines should close on previous- ixed points.

nd. When the "closed polygons" have been drawn for all the points one, it will be found that the "closed Polygon" for the last point is complete.

f both these conditions are not satisfied, this indicates either (1) that ilibrium (under the preliminary hypothesis) is impossible* under the icular loading; or (2), that the investigation is incorrect; or (3), that diagram is inaccurately drawn.

f both these conditions are satisfied, this indicates

1). That equilibrium is possible.

2). That the investigation is correct.

3). That the drawing is accurate.

95. Stress-diagrams for Vertical Load and Normal Load.—As ady indicated in Art. 567, the Loads on Roofs naturally divide them- es into *two* sets.—(1), the Vertical Load, and (2), the Normal Load; l it is not *convenient* to apply the method to both at once. Hence *two* inct Stress-diagrams must be drawn, one for each system of Load. In sequence of the vertical Load being usually *symmetrically* distributed r the Roof, and the Normal Load distributed *over one side only*, the ess-diagram for Vertical Load will usually be found much *easier* of cution in consequence of its symmetry, than that for Normal Load, ich frequently assumes strange and unexpected shapes. A glance at Stress-diagrams which follow will at once show this. Nevertheless, *principle* of construction of each is precisely the same.

Moreover, in *unsymmetrical* Roofs the Stresses due to Wind blowing m right or left will be *different*, so that *separate* Stress-diagrams will required.

In *symmetrical* Roofs, one Stress-diagram will suffice as the Stress on rs *similarly situate* with respect to the Winds can be inferred to be *alike*.

596. Total Working Stress (*see* Art. 456).—The fundamental

* A good instance of this will be seen in the Construction of the Stress-diagram for Normal Load of Ex. 10.

principle of "Design" is that every portion of a Structure must be able to bear the *greatest* Stress to which it can be exposed, and must also be able to bear *at all times* the 'Permanent Stresses'.

Now the Accidental Load being due to Wind which blows *from only one quarter at a time* produces effects, *i. e.*, Stresses, differing generally in *Magnitude*, and sometimes even in *Character* (as to Tension or Thrust) according as it blows from *either* side, and therefore sometimes different in *character* to the Permanent Stresses.

Hence the following important result:—"The WORKING STRESS on any bar must be considered as the 'Permanent Stress' together with either that 'Accidental Stress' which is of the *same* character, or the *greater* of the two 'Accidental Stresses' when *both* are of the *same* character with it; or, lastly, simply as the 'Permanent Stress' when both 'Accidental Stresses' are of *opposite* character to the 'Permanent Stress'.

In certain *exceptional* cases of *very light* Roofs in which, therefore, the Permanent and Accidental Loads are more nearly equal, it may happen that the *Resultant Stress* on certain bars, *i e.*, the "Difference between the Permanent Stress and the *greater* of the two Accidental Stresses" is of *opposite* character to the Permanent Stress. In this case these Bars must of course be designed to bear Working Stresses of both characters, (Tension and Thrust) one of which is equal to the Permanent Stress, and the other to the Resultant Stress just indicated.

Instances of like nature, in which certain parts of a Structure have to be designed to bear a Stress sometimes Tensile, sometimes Crushing, occur frequently in Large Girders, in which, as will be explained hereafter, the Braces near the middle of the Girder are sometimes in Tension, sometimes in Compression, according to the position of the Rolling or Live Load, the Live Load in this case of a Roof being of course the Wind itself.

EXAMPLES OF METHOD ii.

597. As it is wished to make this Treatise available as a work of reference (as well as a mere Text-book for Students) the Stress-diagrams for a great many of the ordinary forms of Roof Trusses have been drawn to scale, and are here inserted with sufficient descriptive letter-press to make them intelligible, and with the General Formulæ in each case.

For the sake of the Student the method of constructing the Stress diagrams has in a few cases (Ex. 1, 2, 5, 10) been very fully explained, and in

the remainder the outline only of the Steps necessary is indicated. The Student is recommended to thoroughly master the method explained in Ex. 1 and 2, and then endeavor to construct the remainder himself, using the printed Stress-diagrams only as a guide.

Spans.—The Span figured on each Frame-diagram may be taken as being about that for which that Truss is suited.

Timber and *Iron.*—*Figs.* 16, 19, 25 are examples of Trusses suitable for Timber, and *Figs.* 18 to 24 for Iron.

Direct Stresses.—The External Loads are in these examples supposed applied to the Principal Rafters by Purlins *at each joint* only, so that the Principal Rafters are not subject to Transverse Strain (*see* Art. 560), and the Problem is limited to that of finding the Direct Stresses (*see* Art. 562 (1)).

General Notation.—*See* Arts. 577, 578.

Intervals of Trusses, Loads, Scales, Slopes.—For *facility of comparison* the *Slopes* of Rafters (i), *Interval between Trusses* (B), *Intensity of Loading* (w and w'), and *Scales*, have been taken the same in *all* the examples of this method, as follows:—

Inclination of rafters, $i = \tan^{-1} \frac{3}{4}$ = about 36° 52', being such that the "Rise" of the Roof (k), the Semi-span (c), and the Rafter (L) form the well known right-angled triangle whose sides are $k : c : L = 3 : 4 : 5$, so that the dimensions of the roof are *easily* calculated in round numbers.

Hence $\cot i = \frac{4}{3}$, $\operatorname{cosec} i = \frac{5}{3}$, $\sec i = \frac{5}{4}$, $\cot 2i = \frac{7}{24}$, $\operatorname{cosec} 2i = \frac{25}{24}$

Also $L = \frac{5}{4}c = \frac{5}{8} \times$ Span (in feet).

Interval between Trussses, B = 10 feet, throughout.

Vertical Load-intensity (w), a uniformly-distributed Load all over the roof of

$$\left.\begin{array}{llll} 40 \text{ lbs. per square foot, weight of roofing,} & & & \\ 5 \text{ lbs.} & \text{"} & \text{"} & \text{rafters, purlins, \&c.,} \\ 5 \text{ lbs.} & \text{"} & \text{"} & \text{absorbed rain, \&c.,} \end{array}\right\} \therefore w = 50 \text{ lbs. per square foot.}$$

Load at vertex of truss (W) carried by ridge pole = 500 lbs.

Load at tie-rod joints (W') = 1000 lbs.

Wind-pressure (*see* Art. 566) as 40 lbs. per square foot of a vertical surface, equivalent to $w' = 30$ lbs. per square foot (*see* Table at end of Art. 566) *normal* to roof of slope $i = 36° 52'$.

$$\left.\begin{array}{l} \text{Hence } W = 50 \times 10' \times 2L = 1000 \times L \text{ pounds} \\ \qquad W' = 30 \times 10' \times L = 300 \times L \text{ pounds} \end{array}\right\} \text{Eq. (12) of Art. 578.}$$

Vertical Re-actions in *symmetrically loaded* roofs are each $= \frac{1}{2}$ Load, ... } Eq. (16) of Art. 578.

Normal Re-actions in *straight-raftered symmetric* roofs are
$$R' = W'(1 - \tfrac{1}{4}\sec^2 i) = \tfrac{23}{32}\,.\,W',$$
$$R'' = W'\,.\,\tfrac{1}{4}\sec^2 i \qquad = \tfrac{9}{32}\,W',$$
} Eq. (18) of Art. 58.

Scales.—Frame-diagrams are on scale of 20 feet to an inch.

Stress-diagrams (for Vertical Load) are on Scale of 8,000 lbs. to an inch.

Stress-diagrams (for Normal Load) are on Scale of 4,000 lbs. to an inch.

Thus, *for these particular numerical values* of w, w', W, W', i, all the Stresses may be immediately taken off the Stress-diagrams *by measurement* from the scale.

N.B.—In consequence of the Vertical and Normal Loads being so different (W $= 3\frac{1}{4}$ W') it was impossible to draw *both* on one scale so as to be distinct and also confined to the limits of the page. Hence in comparing the Stresses due to Vertical and Normal Loads in these Stress-diagrams, *e.g.*, in adding the two Stresses on any Bar (as in Art 596), regard must be had to the difference of scale.

General Formulæ.—For purposes *of general reference*, the trigonometrical formulæ (when not very complicated) are also given, in a *general* form applicable to Roofs of *any* slope: they will be found to be *readily* deducible from the Stress-diagrams.

Diagrams.—Two Diagrams are necessary for each distribution of Load, viz., a Frame-diagram for Step I., and a Stress-diagram for Step II., thus four Diagrams are required for symmetrical Roofs, and six Diagrams for unsymmetrical Roofs, viz. (*see* Art. 595).

For Vertical Load, one Frame- *and one Stress-diagram.

For Normal Load on *Symmetrical* Roofs, } One Frame- *and one Stress-diagram.

For Normal Load on *Unsymmetrical* Roofs, } One Frame- *and one Stress-diagram for Wind on *either* side.

The set of Diagrams for *one* Roof all bear the *same* distinguishing number with the addition of the letters (*a*), (*b*), (*c*), (*d*), &c., to distinguish the kind of Diagram (*i. e*, Frame-diagram or Stress-diagram, under Vertical or Normal Load).

Magnitudes of the Stresses.—These can be *calculated* from the general formulæ given, or obtained *at once by measurement* from the Stress-diagrams —(a special diagram is of course necessary for the particular Roof and particular Loading proposed in any case)—*with quite sufficient accuracy*

* After a little practice, *one* Frame-diagram can be made to serve for *all* the cases.

for practical purposes. Calculation from the formula is of course more exact, but this exactness is, in consequence of the uncertainty of many of the data, quite unnecessary: the magnitudes of the Stresses are really required only in round numbers in practice.

It has not been thought necessary to give the numerical values of the Stresses in the Examples, except as an illustration of the method of combining the *two* Stresses (Art. 596) on each Bar, (viz., 1°, That due to Vertical Load; 2°, That due to Wind-pressure on *either* side), so as to obtain the *Total* "Working Stresses".

This has been done only in Ex. 1 and 8.

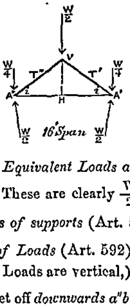
Example 1.

Description.—A simple symmetrical triangular Truss of 16′ span.

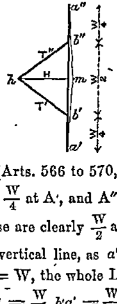
Conditions and *Notation* (*see* Arts. 577, 578, 597).—W = 10,000 lbs., W′ = 3,000 lbs.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 16 (*a*).



Stress-diagram, *Fig.* 16 (*b*).



Step I. *Equivalent Loads at the joints* (Arts. 566 to 570, 578).

These are clearly $\frac{W}{2}$ at V, and $\frac{W}{4}$ at A′, and A″.

Re-actions of supports (Art. 571).—These are clearly $\frac{W}{2}$ at A′ and A″.

Polygon of Loads (Art. 592).—On any vertical line, as $a''a'$, (vertical because the Loads are vertical,) take $a''a' = W$, the whole Load.

On $a''a'$ set off *downwards* $a''b'' = \frac{W}{4}$, $b''b' = \frac{W}{2}$, $b'a' = \frac{W}{4}$, representing the Vertical Loads at the joints A″, V, A′; $a''a'$ is called the Load line.

On $a'a''$ set off *upwards* $a'm = \frac{W}{2}$, $ma'' = \frac{W}{2}$, representing the Reactions at A′, A″, respectively.

Then $a''b''b'a'mb''$ is a *closed* polygon representing *all* the external vertical forces, which are therefore *in equilibrium* (Art. 590, 1°); this is called the "Polygon of Loads."

N.B.—The Re-actions $a'm$, ma'' have been slightly *splayed* from the "Load Line" $a''a'$ (as explained in Art. 592) simply to indicate clearly *to the eye* that the really *overlapping* lines $a''b''b'a'$, $a'ma''$ are merely the *limit* of a Polygon.

STEP. II. *Resolution of Loads at the joints* (Art. 593).—Draw the "polygon of forces" in equilibrium (Art. 590, 2°) for each joint *in succession*.

Joint A′.—The forces are the Load $\frac{W}{4} = b'a'$, Re-action $\frac{W}{2} = a'm$, and two Stresses H, T′, whose *directions* only are known (parallel to A′A″, VA′).

Draw mh parallel to A′A″, *i. e.*, horizontal.

Draw hb' parallel to VA′ through the point b'.

It follows (from Art. 590, 2°) that $b'a'mhb'$ is the *closed* polygon representing the forces in equilibrio at the joint A′.

∴ mh represents H, and being drawn *from m* indicates Tension *at* A′.

hb' represents T′, and being drawn *towards* b' indicates Thrust *on* A′.

Joint A″.—In a precisely similar manner, it will be found that $ma''b''hm$ is the *closed* polygon representing the forces in equilibrio at A″, thus

ma'' represent $\frac{W}{2}$ the Re-action, $a''b''$ represents the Load $\frac{W}{4}$.

∴ $b''h$ represents T″, indicating Thrust on A″.

hm represents H, indicating Tension at A″.

Joint V.—It will now be seen that the "Polygon of Forces" for V is *already complete*. The forces are $\frac{W}{2}$ the Load, and Stresses T′, T″:

But $b''b'$ represents $\frac{W}{2}$ the Load,

$b'h$ represents T′, indicating Thrust on V,

hb'' represents T″, indicating Thrust on V.

Thus $b''b'hb''$ is the *closed* Polygon of Forces in equilibrium at V.

Check on the investigation.—The *closing* of the lines drawn for the joint A″ on those previously drawn for the joint A′ *and* the Polygon for the joint V having been *completed in the act* of drawing those for A′, A″ constitutes the perfect check alluded to in Art. 594.

Magnitudes of the Stresses.—If the Stress-diagram be properly drawn to

scale, then hb', hb'', hm represent T', T'', H, respectively, on that scale, thus

$$T' = 4166\tfrac{2}{3}\text{ lbs.} = T'',\ H = 3333\tfrac{1}{3}\text{ lbs.}$$

General Formulæ.—Trigonometrical formulæ are *easily* derived from the Stress diagram, thus :—

$$\left.\begin{array}{l} T' = hb' = mb' \operatorname{cosec} i, \\ T'' = hb'' = mb'' \operatorname{cosec} i, \end{array}\right\} = \frac{W}{4} \operatorname{cosec} i,\ (\textit{Thrust}).$$

$$H = hm = mb' \cot i, \qquad = \frac{W}{4} \cot i,\ (\textit{Tension}).$$

On calculating these *numerically* for any particular loading they will of course be found exactly the same as the values obtained by measurement from the scale.

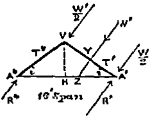
Character of Stress (Art. 593).—Observe that the *direction* in which the lines representing the Stresses are drawn indicates the *character* (as Tension or Thrust) of the Stress, and that the Theorem (Art. 590) of the polygon of forces requires that the sides of the polygon be taken *in order*.

Thus $b'amhb'$, $ma''b''hm$, $b''b'hb''$ are the polygons for the joints A', A'', V, respectively, so that

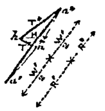
H is represented by mh, hm at the joints A', A'', respectively.
T' ,, hb', $b'h$,, A', V ,,
T'' ,, $b''h$, hb'' ,, A'', V ,,

Construction for *Normal Load.*

Frame-diagram, *Fig.* 16 (*c*).



Stress-diagram, *Fig.* 16 (*d*).



STEP I. *Equivalent Loads at the joints* (Arts. 566 to 570, 578).—These are clearly $\frac{W'}{2}$ at V and $\frac{W'}{2}$ at A' (the Wind being supposed blowing from the *right*, *i. e.*, on Rafter VA').

Re-actions of supports. (Arts. 571, 578).—These are

$$R' = \frac{39}{64} W' \text{ at } A';\ R'' = \frac{25}{64} W' \text{ at } A''.$$

Polygon of Loads (Art. 592).—On any line as $a''a'$ parallel to the Wind's direction (YZ), and therefore perpendicular to the Rafter VA', take $a''a' = W'$, the whole Load.

On $a''a'$ set off *downwards* $a''m = \frac{W'}{2}$, $ma' = \frac{W'}{2}$ representing the Loads at the joints V, A'; $a''a'$ is called the LOAD LINE.

On $a'a''$ set off *upwards*, $a'z = R'$, $za'' = R''$ representing the Re-actions at A', A'', respectively.

Then $a''ma'za''$ is a *closed* Polygon representing *all* the external forces which are therefore *in equilibrium* (Art. 590, 1°); this is called the "Polygon of Loads."

N.B.—The Re-actions $a'z$, za'' have been slightly *splayed* from the "Load-line" $a''a'$ for the reason explained at end of Art. 592.

STEP II. *Resolution of Loads at the joints* (Art. 593).—Draw the "Polygon of Forces" in equilibrium (Art 590, 2°) for each joint *in succession.*

Joint A'.—The forces are the Load $\frac{W'}{2} = ma'$, Re-action $R' = a'z$, and two Stresses H, T' whose *directions* only are known (parallel to A'A'', VA').

Draw zh parallel to A'A'', *i. e.*, horizontal.

Draw mz parallel to VA', *i. e.*, $\perp^r$ to $a''a'$.

It follows (from Art. 590, 2°) that $ma'zhm$ is the *closed* polygon representing the forces in equilibrium at the joint A'.

$\therefore$ zh represents H, and being drawn *from* z indicates Tension *at* A'.

hm represents T', and being drawn *towards* m indicates Thrust *on* A'.

Joint A''.—The forces are the Stress H, and Re-action $R'' = za''$, and the Stress T'' whose *direction* only is known (parallel to VA'').

Draw $a''h$ parallel to VA''; if the investigation be correct so far, this should pass through the point h.

It follows (from Art. 590, 2°) that $hza''h$ is the *closed* polygon representing the forces in equilibrium at the joint A''.

$\therefore$ $a''h$ represents T'', and being drawn *towards* h indicates Thrust *on* A''.

Joint V.—It will now be seen that the "Polygon of Forces" for V is *already complete.* The forces are $\frac{W'}{2}$ the Load represented by $a''m$.

T' the Stress in A'V, represented by mh, indicating Thrust on V.

T'' the Stress in A''V, represented by ha'', indicating Thrust on V.

Thus $a''mha''$ is the *closed* Polygon of Forces in equilibrium at V.

Check on the investigation.—The same remarks apply as to the Stress-diagram for Vertical Load, *q v.*

Magnitudes of the Stresses.—If the Stress-diagram be properly drawn to

scale, then hm, ha'', hz represent T′, T″, H, *respectively, on that scale,* thus $T' = 437\frac{1}{2}$ lbs., $T'' = 1562\frac{1}{2}$ lbs., $H = 546\frac{7}{8}$ lbs.

General Formulæ are *easily* derived from the Stress-diagram, thus

$$T' = hm = mz \, . \cot mhz = \left(R' - \frac{W'}{2}\right) . \cot i, \ (\textit{Thrust}).$$

$$T'' = ha'' = a''m \operatorname{cosec} a''hm = \frac{W'}{2} . \operatorname{cosec} 2\,i = \frac{W'}{4} \cdot \sec i \operatorname{cosec} i, (\textit{Thrust}).$$

$$H = hz = mz \, . \operatorname{cosec} mhz = \left(R' - \frac{W'}{2}\right) \operatorname{cosec} i, \ (\textit{Tension}).$$

On calculating these *numerically* for any particular loading, they will of course be found exactly the same as the values obtained by measurement from the scale.

N.B.—These Stresses are those due to a Wind blowing from the *right* only. In consequence of the *symmetry* of the Roof it can be at once inferred that for a Wind blowing from the *left* H is *unchanged*, and T′, T″ *interchange* magnitudes.

Total Working Stresses.

These are easily found by the principles laid down in Art. 596, but they are better exhibited *numerically* than in formulæ. Thus combining the Stress due to the permanent (Vertical) Load, and the *Greatest* of the stresses, due to the accidental (Normal) Load, *i. e.*, the Wind on *either* side, we obtain (for the particular values of w, w', i assigned).

BAR.	Stress.	STRESSES IN POUNDS.		Total Working Stress in pounds.	Character.
		Due to Vertical Load.	Greatest due to Wind.		
Rafter, VA′ or VA″, ..	T′ or T″	$4166\frac{2}{3}$	$1562\frac{1}{2}$	$5729\frac{1}{6}$	Thrust.
Tie-rod, A′A″, ...	H	$3333\frac{1}{3}$	$546\frac{7}{8}$	$3880\frac{5}{24}$	Tension.

Practical Remark.—Note that the equilibrium is *complete*, and that the Truss is therefore complete without introduction of any additional *Bars*: *e. g.*, if a king-rod were added in the position VH, it would be *unstrained* (under the given conditions of Load), and therefore *useless*. If the Load be altered in any way, *e. g.*, by suspending an additional Load w′ at the joint H (say a *heavy* lamp), then a king-rod HV would be required to

prevent the tie-rod A'A" bending unduly: the Stress on this king-rod would be simply = w'.

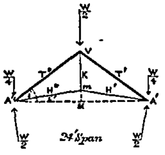
Example 2.

Description.—A symmetrical triangular Truss of 24' span with the Tie-rod slightly braced up to inclination *i'* by a king-rod.

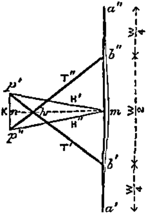
Conditions and *Notation* (*see* Arts. 577, 578, 597).—W = 16,000 lbs., W = 4,500 lbs.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 17 (*a*).



Stress-diagram, *Fig.* 17 (*b*).



Step I. *Polygon of Loads, a"b"b'a'ma"* constructed exactly as in Ex. 1.

Step II. *Resolution of Loads at joints*

Joints A', A".—*b'a'mp'b', ma"b"p"m* are the closed "Polygons of forces" in Equilibrium at A', A" constructed exactly as for the joints A', A" in Ex. 1, noting that *mp'*, *p"m* are of course drawn parallel to the *inclined* tie-rods A'*m*, A"*m*.

Joint m—The forces are H' = *p'm*, H" = *mp"* (both drawn), and K known only in *direction* (being vertical). Join *p"p'* which (if the figure be *correctly* drawn) will be vertical, so that

p'mp"p' is the *closed* Polygon of forces in equilibrium at *m*.

∴ *p"p'* represents K, and being drawn *from p"* indicates Tension *at m*.

Joint V.—It will now be seen that the Polygon of Forces for V, viz, *b"b'p'p"b"* is already *complete*. The forces are the Load $\frac{W}{2}$, and the Stresses T', K, T",

But *b"b'* represents the Load $\frac{W}{2}$,

b'p' represents T', indicating Thrust on V.

p'p" represents K, indicating Tension on V.

p"b" represents T", indicating Thrust on V.

Check on the investigation.—The verticality of the line *p'p"*, and the Polygon for

the joint V having been *completed* in the act of drawing the Polygons for the previous joints constitute the "check" (*see* Art. 594).

General Formulæ are *easily* derived from the Stress diagram.

The symmetry of the figure shows that mhn bisects and is $\perp^r$ to $p'p''$.

$$T' = b'p' = mb'.\frac{\sin b'mp'}{\sin b'p'm} = \frac{W}{4}.\frac{\sin(90 + i')}{\sin(i - i')} = \frac{W}{4}.\frac{\cos i'}{\sin(i - i')}, (\textit{Thrust}).$$

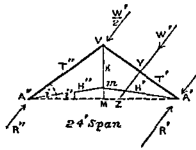
$$H' = mp' = mb'.\frac{\sin mb'p'}{\sin mp'b'} = \frac{W}{4}.\frac{\sin(90 - i)}{\sin(i - i')} = \frac{W}{4}.\frac{\cos i}{\sin(i - i')}, (\textit{Tension}).$$

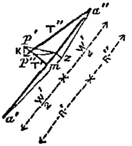
$$K = p''p' = 2np' = 2mp'.\sin p'mn = 2H'.\sin i', (\textit{Tension}).$$

Evidently $T' = T''$, and $H' = H''$.

- *Construction* for *Normal Load.*

Frame-diagram, *Fig.* 17 (*c*). Stress-diagram, *Fig.* 17 (*d*).





$p'z = H'$, $p''z = H''$.

STEP I. *Polygon of Loads*, $a''ma'za''$ constructed exactly as in Ex. 1.

STEP II. *Resolution of Loads at joints.*

Joints A', A''.—$ma'zp'm$, $za''p''z$ are the *closed* "Polygons of Forces" in equilibrium at A', A'', constructed exactly as for the joints A', A'' in Ex. 1, noting that zp', $p''z$ are of course drawn parallel to the *inclined* tie-rods $A'm$, $A''m$.

Joint m.—The forces are $H' = p'z$, $H'' = zp''$ (both drawn), and K known only in *direction* (being vertical). Join $p''p'$ which (if the figure be correctly drawn) will be vertical, so that

$p'zp''p'$ is the *closed* Polygon of Forces in equilibrium at m.

∴ $p''p'$ represents K, and being drawn *from* p'' indicates Tension *at* m.

Joint V.—It will now be seen that the Polygon of Forces $a''mp'p''a''$ for this joint is already *complete*. The forces are the Load $\frac{W'}{2}$, and the Stresses T,, K, T''.

But $a''m$ represents the Load $\frac{W}{2}$.

mp' represents the Stress T', indicating Thrust on V.

$p'p''$ represents the Stress K, indicating Tension at V.

$p''a''$ represents the Stress T'', indicating Thrust on V.

Check on the Investigation.—The verticality of the line $p'p''$, and the Polygon for the joint V having been *completed* in the act of drawing the Polygons for the previous joints, constitute the check (Art. 591).

General Formulæ are easily derived from the Stress-diagram.

$T' = mp' = mz \,.\, \cot zp'm = \left(R' - \frac{W'}{2}\right) \cot (i - i')$, (*Thrust*).

$H' = zp' = mz \,.\, \operatorname{cosec} zp'm = \left(R' - \frac{W'}{2}\right) . \operatorname{cosec} (i - i')$, (*Tension*).

$H'' = H'$ for the lines zp', zp'' are equally inclined to the vertical $p'p''$.

$T'' = p''a'' = za'' . \frac{\sin p''za''}{\sin zp''a''} = R'' . \frac{\sin (90 + i + i')}{\sin (i - i')} = R'' . \frac{\cos (i + i')}{\sin (i - i')}$, (*Thrust*).

$K = p'p'' = 2\, p'z \,.\, \sin \frac{p'zp''}{2}$, (for $p'zp''$ is an isosceles triangle) $= 2\, H' . \sin i'$, (*Tension*).

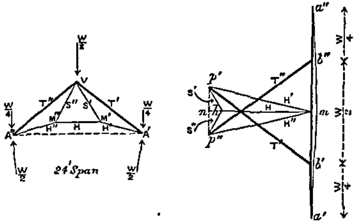
Example 8.

Description.—A symmetrical triangular Truss of 24′ span with the Tie-rod slightly braced up to inclination i' by two braces, VM′, VM″, such that A′M′V, A″M″V are isosceles triangles.

Conditions and *Notation* (*see* Arts. 577, 578, 597).—W = 15,000 lbs., W′ = 4,500 lbs.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 18 (*a*). Stress-diagram, *Fig.* 18 (*b*).



STEP I. *Polygon of Loads* $a''b''b'a'ma''$ as in Ex 1.

STEP II. *Resolution of Loads at Joints.*

The Polygons of Forces in equilibrium at each joint are

$b'a'mp'b'$ for the joint A′; $ma''b''p''m$ for the joint A″.
$p'mhp'$ for the joint M′; $mp''hm$ for the joint M″.
$b''b'p'hp''b''$ for the joint V.

The check on the work is obvious, (Art. 594).

General Formulæ.—*See* the Frame- and Stress-diagrams.

$M'A'A'' = i' = M''A''A'$; $p'mh = i' = p''mh$.

$M'A'V = i - i' = M'VA'$; $mp'h = 180° - A'M'V = 2\,(i - i')$.

$M''A''V = i - i' = M''VA''$; $mhp' = 180° - (p'mn + mp'h) = 180 - (2i - i')$

$$T' = p'b' = mb' \cdot \frac{\sin p'mb'}{\sin mp'b'} = \frac{W}{4} \cdot \frac{\sin(90^\circ + i')}{\sin(i - i')} = \frac{W}{4} \cdot \cos i' \cdot \operatorname{cosec}(i - i'), (\textit{Thrust}).$$

$$H' = mp' = mb' \cdot \frac{\sin mb'p'}{\sin mp'b'} = \frac{W}{4} \cdot \frac{\sin(90 - i)}{\sin(i - i')} = \frac{W}{4} \cdot \cos i \cdot \operatorname{cosec}(i - i'), (\textit{Tension}).$$

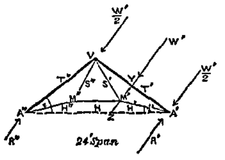
$$H = mh = mp' \cdot \frac{\sin mp'h}{\sin mhp'} = H' \cdot \frac{\sin 2(i - i')}{\sin(2i - i')}, (\textit{Tension}).$$

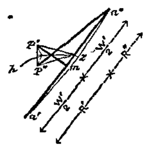
$$S' = hp' = mp' \cdot \frac{\sin hmp'}{\sin mhp'} = H' \cdot \frac{\sin i'}{\sin(2i - i')}, (\textit{Tension}).$$

Also by the symmetry of the figure $T' = T''$; $H' = H''$; $S' = S''$.

Construction for *Normal Load.*

Frame-diagram, *Fig.* 18 (*c*). Stress-diagram, *Fig.* 18 (*d*).





STEP I. *Polygon of Loads*, $a''ma'za''$ as in Ex. 1.

STEP II. *Resolution of Loads at joints.*—The Polygons of forces in equilibrium at each joint are

$ma'zp'm$ for joint A'; $za''p''z$ for joint A''.
$p'zhp'$ for joint M'; $hzp''h$ for joint M''.
$a''mp'hp''a''$ for joint V.

The check on the work is obvious.

General Formulæ.—*See* Frame- and Stress-diagrams.

$$T' = p'm = mz \cot mp'z = \left(R' - \frac{W'}{2}\right) \cdot \cot(i - i'), (\textit{Thrust}).$$

$$H' = zp' = mz \cdot \operatorname{cosec} mp'z = \left(R' - \frac{W'}{2}\right) \cdot \operatorname{cosec}(i - i'), (\textit{Tension}).$$

$$S' = p'h = p'z \cdot \frac{\sin p'zh}{\sin p'hz} = H' \cdot \frac{\sin i'}{\sin(2i - i')}, (\textit{Tension}).$$

$$T'' = p''a'' = a''z \cdot \frac{\sin p''za''}{\sin a''p''z} = R'' \cdot \frac{\sin(90 + i + i')}{\sin(i - i')}$$

$$= R'' \frac{\cos(i + i')}{\sin(i - i')}, (\textit{Tension}).$$

Evidently, also zh produced bisects $p'p''$ (which will be vertical if the figure be correctly drawn) at right angles.

$$\therefore S'' = hp'' = hp' = S'; \; H'' = zp'' = zp' = H'.$$

Practical Remark on Examples 2 and 3.—It is interesting to observe

the effect (which the Stress-diagrams render obvious to the eye) of bracing up the Tie-rod, as compared with the straight Tie-rod in Ex. 1, viz., that the Stresses on the Rafters and Tie-rod are all *increased*, and a King-rod or Braces rendered necessary to bear the vertical component of the Stress on the inclined Ties. The advantage of bracing up the Tie is to gain head-way under the Tie-rod: the construction is suited to Iron Tie-rods, not to Timber.

The *same* effects consequent on bracing up the Tie-rods are seen at a glance in the Stress-diagrams to Ex. 4 and 6, also in Ex. 7, *q.v.*

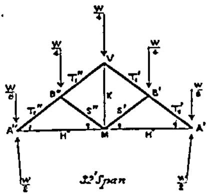
EXAMPLE 4.

Description.—A symmetrical King-post Truss of 32′ span, with Rafters bisected by the Struts.

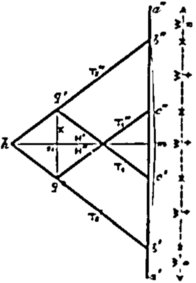
Conditions and *Notation* (*see* Arts. 577, 578, 597).—$W = 20{,}000$ lbs., $W' = 6{,}000$ lbs.

Construction for Vertical Load.

Frame-diagram, *Fig.* 19 (*a*).



Stress-diagram, *Fig.* 19 (*b*).



STEP I. *Equivalent Loads at the joints.*—As there are two equal segments in each Rafter, the Load distributed over each segment is $\frac{W}{4}$, so that the Equivalent Loads at the joints are clearly (*compare* Eq. (15), Art. 576), $\frac{W}{8}$ at the abutments A′, A″; and $\frac{W}{4}$ at the joints B′, V, B″.

Polygon of Loads.—On the Load-line $a''a' = W$, take successively

$$a''b'' = \frac{W}{8},\ b''c'' = c''c' = c'b' = \frac{W}{4},\ b'a' = \frac{W}{8} \text{ for the Loads.}$$

$$a'm = \frac{W}{2} = ma'' \text{ for the Re-actions.}$$

Then $a''b''c''c'b'a'ma''$ is the "Polygon of Loads."

STEP II. *Resolution of Loads at the joints.*—The Polygons of Forces at the joints are as follows, in succession

$b'a'mhb'$ at joint A' ; $ma''b''hm$ at joint A''.
$c'b'hq'c'$ at joint B' ; $hb''c''q''h$ at joint B''.
$q'hmhq''q'$ at joint M. } Note, that H', H'' are represented in the Polygon for
$c''c'q'q''c''$ at joint V. } the point M by hm, mh, respectively, a pair of *overlapping lines.*

The check on the work is obvious, (Art 594).

General Formulæ.

$$T_2' = hb' = mb' \operatorname{cosec} mhb' = (mc' + c'b') \operatorname{cosec} i = \frac{3W}{8} \operatorname{cosec} i, (\textit{Thrust}).$$

$$H' = H'' = mh \doteq mb' \cot mhb' = \frac{3W}{8} \cot i, (\textit{Tension}).$$

$$K = q''q' = b'c' = \frac{W}{4}, (\textit{Tension}).$$

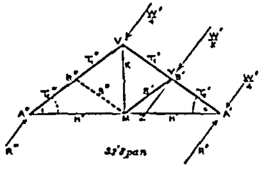
$$S' = hq' = q'n \,.\, \operatorname{cosec} q'hn = \tfrac{1}{2}\, q'q'' \,.\, \operatorname{cosec} i = \frac{W}{8} \operatorname{cosec} i, (\textit{Thrust}).$$

$$T_1' = c'q' = b'q'' = b'h - q''h = T_2' - S'' = \frac{W}{4} \operatorname{cosec} i, (\textit{Thrust}).$$

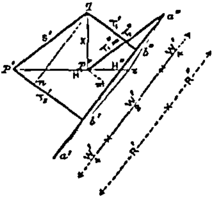
Also evidently $T_1' = T_1''$; $T_2' = T_2''$; $S' = S''$.

Construction for Normal Load.

Frame diagram, *Fig.* 19 (*c*).



Stress-diagram, *Fig.* 19 (*d*).



STEP I. *Equivalent Load at the joints.*—As there are two *equal* segments in the Rafters, the Load distributed over each segment is $\frac{W'}{2}$, so that the Equivalent Loads at the joints are clearly (*compare* Eq (17), Art. 578).

$$\frac{W'}{4} \text{ at A' and V, and } \frac{W'}{2} \text{ at B', and no Load at B'' or A''.}$$

Polygon of Loads.—On the Load line $a''a'$ parallel of course to the Wind-pressure, *i. e.*, perpendicular to the Rafter, take successively

$$a''b'' = \frac{W'}{4},\ b''b' = \frac{W'}{2},\ b'a' = \frac{W'}{4},\ a'z = R',\ za'' = R''.$$

Then $a''b''b'a'za''$ is the "Polygon of Loads."

STEP II. *Resolution of Loads at joints.*—The "Polygon of Forces" at the joints taken in succession are as follows:—

$b'a'zp'b'$ at joint A'; $za''p''z$ at joint A''.
$b''b'p'qb''$ at joint B'; $p''a''p''$ at joint B'' (not loaded).
$qp'zp''q$ at joint M (no stress on bar B''M).
$a''b''qp''a''$ at joint V.

If the diagram be correctly drawn, qp'' will be vertical.

Note particularly that the Polygon of forces for the joint B'' is $p''a''p''$, *i. e.*, simply a pair of overlapping lines, because the joint B'' is *not loaded;* hence $T_1'' = T_2''$ and $S'' = 0$, *i. e*, there is no Stress on the Strut B''M. These results might have been foreseen from the general considerations explained in Art. 575.

General Formulæ.

$$T_2' = p'b' = zb'.\cot.zp'b' = \left(R' - \frac{W'}{4}\right)\cot i,\ (\textit{Thrust}).$$

$$H' = zp' = zb'.\ \text{cosec}\ zp'b' = \left(R' - \frac{W'}{4}\right).\text{cosec}\ i,\ (\textit{Tension}).$$

$$T_1'' = T_2'' = p''a'' = a''z.\frac{\sin p''za''}{\sin a''p''z} = R''.\frac{\sin(90° + i)}{\sin i}$$
$$= R''.\cot i = \frac{W'}{4}.\sec^2 i.\cot i = \frac{W'}{2}.\text{cosec}\ 2i,\ (\textit{Thrust}).$$

$$H'' = zp'' = a''z\ \frac{\sin za''p''}{\sin a''p''z} = R''.\frac{\sin(90 - 2i)}{\sin i} = R''\frac{\cos 2i}{\sin i},\ (\textit{Tension}).$$

$$S' = p'q = b'b''.\text{cosec}\ qp'b' = \frac{W'}{2}\ \text{cosec}\ 2i,\ (\textit{Thrust}).$$

$$K = qp'' = qp'.\sin\ qp'p'' = S'.\sin i = \frac{W'}{2}.\frac{\sin i}{\sin 2i} = \frac{W'}{4}.\sec i,\ (\textit{Tension}).$$

$$T_1' = qb'' = p'b' - p'n = p'b' - qn.\cot qp'n =$$
$$= T_2' - \frac{W'}{2}.\cot 2i,\ (\textit{Thrust}).$$

Practical Remarks.—On comparing the Stress-diagrams of this Example with Examples 1, 2, 3, it will be found that with a *straight* Tie-rod there can be *no Stress* on a King-rod (except that due to its own weight, and that due to sagging of the Tie-rod under its weight, both small in small Trusses,) *unless* the Tie-rod be loaded (*see* Remarks at end of Ex. 1), and that bracing the Tie-rod or strutting the Rafters throws Stress on the King-rod or internal Bracing.

EXAMPLE 5.

Description.—A symmetrical King-post Truss, as in Ex. 4.

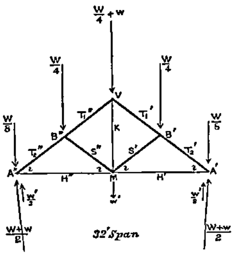
Condition and *Notations* (*see* Arts. 577, 578, 597).—W = 20,000 lbs., w = 500 lbs., w' = 1,000 lbs., W' = 6,000 lbs.

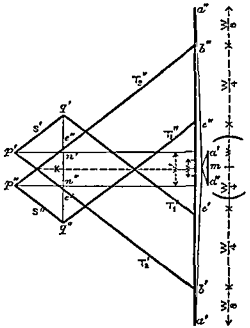
N.B.—The Truss is the *same* as in Ex. 4. The Vertical Load alone differs from that of Ex. 4 in that the Loads w, w' have been added on the Ridge, and at foot of king-rod.

This Truss is therefore loaded as in Example of Method i., Art. 580.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 20. (*a*). Stress-diagram, *Fig.* 20 (*b*).





STEP I. *Polygon of Loads.*—The "Equivalent Loads" at the joints are the *same* as in Ex. 4, except that there is a Load of $\left(\frac{W}{4} + w\right)$ on V, and a Load of w' on M.

The Re-actions are $\frac{W + w + w'}{2}$ at A' and A".

In cases (like the present) in which there are Loads *both* on the Rafters and Tie-rod, it will be found convenient to represent their Loads on *different* Load-lines, thus—

Take $a''a'$ to represent (W + w) the Total Load on Rafters, and $a'a, a''a''$ to represent the Re-actions $\frac{W + w + w'}{2}$ at A', A"; the lines $a'a', a''a''$ will clearly overlap by the quantity $a'a'' = w'$ which may be taken as the Load-line representing w'.

On $a''a'$ set off $a''b'' = \frac{W}{8}$, $b''c'' = \frac{W}{4}$; $c''c' = \left(\frac{W}{4} + w\right)$; $c'b' = \frac{W}{4}$; $b'a' = \frac{W}{8}$

Hence $a''b''c''c'b'a'a'a''a''$ is the Polygon of Loads.

N.B.—The Load lines $a''a', a'a''$ and Re-actions $a'a', a''a'$ have been purposely splayed outwards for the reason explained at end of Art. 592.

STEP II. *Resolution of Loads at the joints.*—The Polygons of Forces for the joints in succession are

$b'a'a'p'b'$ for joint A'; $a''a''b''p''a''$ for joint A''.
$c'b'p'q'c'$ for joint B'; $p''b''c''q''p''$ for joint B''.
$q'p'a'a''p''q''q'$ for joint M, $\left\{\begin{array}{l}\text{at which the forces } \textit{taken in order} \\ \text{are S}', \text{H}', \text{W}', \text{H}'', \text{S}'', \text{K}.\end{array}\right.$
$c''c'q'q''c''$ for joint V.

General Formulæ.

$$T_2' = p'b' = a'b' \cdot \text{cosec}\, a'p'b' = (a'm + mb') \text{ cosec } i.$$
$$= \left(\frac{a'a''}{2} + \frac{c'c''}{2} + c'b'\right) \cdot \text{cosec } i = \left\{\frac{W'}{2} + \frac{1}{2}\left(\frac{W}{4} + W\right) + \frac{W}{4}\right\} \text{cosec } i.$$
$$= \left(\frac{3W}{8} + \frac{W + W'}{2}\right) \text{cosec } i, \ (\textit{Thrust}).$$

$$H' = a'p' = a'b' \cdot \cot a'p'b' = \left(\frac{3W}{8} + \frac{W + W'}{2}\right) \cot i, \ (\textit{Tension}).$$

$$S' = p'q' = q'n' \cdot \text{cosec}\, q'p'n' = \frac{q'c'}{2} \cdot \text{cosec } i = \frac{c'b'}{2} \cdot \text{cosec } i = \frac{W}{8} \text{cosec } i, \ (\textit{Thrust}).$$

$$K = q'q'' = (q'n' + n'n'' + n''q'') = (2q'n' + a'a'') = \left(\frac{W}{4} + W'\right), \ (\textit{Tension}).$$

$$T_1' = q'c' = c'b' = p'b' - p'c' = T_2' - S' = \left(\frac{W}{4} + \frac{W + W'}{2}\right) \cdot \text{cosec } i, \ (\textit{Thrust}).$$

Also evidently $T_1' = T_1''$; $T_2' = T_2''$; $S' = S''$; $H' = H''$.

The Student is recommended to compare the process in this Example with the process by the Method i of Resolution for the same Roof, (*see* Arts. 580 to 583); the greater facility of this Method (the Polygonal) will be at once evident. The results obtained by both methods are of course *identical*, (*see* Art. 584).

He should also compare the Stress-diagrams for Vertical Load of Examples 4 and 5 (*Figs* 19 (*b*) and 20 (*b*)), which are examples of the *same* Truss under slightly different Load, to see the effect of adding the Loads W and W' on the Ridge and Tie-rod.

Construction for Normal Load.

This Truss being the *same* as in Ex. 4, and under the *same* Normal Load, no separate investigation is needed.

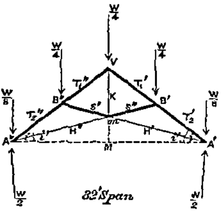
EXAMPLE 6.

Description.—A symmetrical King-post Truss of 32' span, the Rafters bisected by the Struts, the Ties braced up so as to be in one line with the Struts.

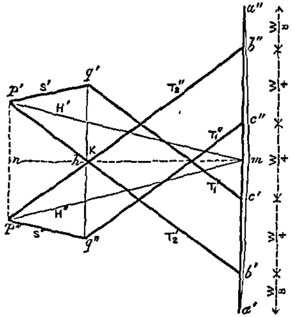
Conditions and *Notation* (*see* Arts. 577, 578, 597).—$W = 20{,}000$ lbs, $W' = 6{,}000$ lbs.

Construction for Vertical Load.

Frame-diagram, *Fig.* 21 (*a*).



Stress-diagram, *Fig.* 21 (*b*).



STEP I. *Polygon of Loads*, $a''b''c''c'b'a'ma''$ as in Ex. 4.

STEP II. *Resolution of Loads at joints.*—The Polygons of Forces for the joints taken in succession are

$b'a'mp'b'$ for joint A';	$ma''b''p''m$ for joint A''.
$c'b'p'q'c'$ for joint B';	$p''b''c''q''p''$ for joint B''.
$q'p'mp''q''q'$ for joint m;	*N.B.*—$q'q''$ should be vertical.
$c''c'q'q''c''$ for joint V.	

General Formulæ.

$$T_2' = p'b' = mb' \cdot \frac{\sin p'mb'}{\sin mp'b'} = \frac{3W}{8} \cdot \frac{\sin (90 + i)}{\sin (i - i')} = \frac{3W}{8} \cdot \cos i' \cdot \operatorname{cosec} (i - i'), \text{ (\textit{Thrust})}.$$

$$H' = mp' = mb' \cdot \frac{\sin mb'p'}{\sin mp'b'} = \frac{3W}{8} \cdot \frac{\sin (90 - i)}{\sin (i - i')} = \frac{3W}{8} \cos i \cdot \operatorname{cosec} (i - i'), \text{ (\textit{Tension})}.$$

$$K = q'q'' = 2\,q'h = 2\,c'b' = \frac{W}{2}, \text{ (\textit{Tension})}.$$

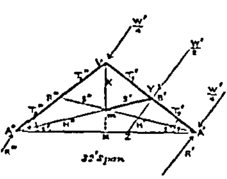
$$S' = p'q' = q'h \cdot \frac{\sin p'hq'}{\sin q'p'h} = c'b' \cdot \frac{\sin (90 - i)}{\sin (i + i')} = \frac{W}{4} \cdot \frac{\cos i}{\sin (i + i')}, \text{ (\textit{Thrust})}.$$

$$T_1' = q'c' = hb' = mb' \cdot \operatorname{cosec} \; mhb' = \frac{3W}{8} \operatorname{cosec} i, \text{ (\textit{Thrust})}.$$

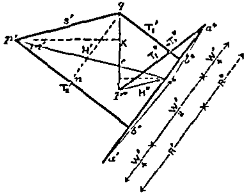
Also evidently $T_1' = T_1''$; $T_2' = T_2''$; $H' = H''$; $S' = S''$.

Construction for Normal Load.

Frame-diagram, *Fig.* 21 (*c*).



Stress-diagram, *Fig.* 21 (*d*).



STEP I. *Polygon of Loads*, $a'b''b'a'za''$ as in Ex. 4.

STEP II. *Resolution of Loads at joints.*—The "Polygons of Forces" for the joints taken in succession are

$b'a'zp'b'$ for joint A' ; $za''p''z$ for joint A''
$b''b'p'qb''$ for joint B' ; $p''a''p''$ for joint B'' (not loaded).
$qp'zp''q$ for joint m (no Stress on bar B''m).
$a''b''qp''a''$ for joint V.

General Formulæ.

$$T_2' = p'b' = zb' . \cot zp'b' = \left(R' - \frac{W'}{4}\right) \cot (\iota - \iota'), (\textit{Thrust}).$$

$$H' = zp' = zb' . \operatorname{cosec} zp'b' = \left(R' - \frac{W'}{4}\right) . \operatorname{cosec} (\iota - \iota'), (\textit{Tension}).$$

$$S' = p'q = qn . \operatorname{cosec} qp'n' = \frac{W'}{2} . \operatorname{cosec} (\iota + \iota'), \textit{Thrust}).$$

$$T_1' = qb' = p'b' - p'n = p'b' - qn . \cot qp'n = T_2' - \frac{W'}{2} . \cot (\iota + \iota'), (\textit{Thrust}).$$

$$T_1'' = T_2'' = p''a'' = za'' . \frac{\sin p''za''}{\sin zp''a''} = R'' . \frac{\sin (90 + \iota + \iota')}{\sin (\iota - \iota')} = R'' . \frac{\cos (\iota + \iota')}{\sin (\iota - \iota)} , (\textit{Thrust.})$$

$$H'' = zp'' = za'' . \frac{\sin za''p''}{\sin zp''a''} = R'' . \frac{\sin (90 - 2\iota)}{\sin (\iota - \iota')} = R'' . \frac{\cos 2\iota}{\sin (\iota - \iota')} , (\textit{Tension}).$$

$K = qp'' = qe + ep'' = 2S' . \sin \iota' + 2H'' \sin \iota' = 2 (S' + H') . \sin \iota'$, (*Tension*).
for qp'' is vertical, and qp', $p'e$, ez, zp'' are all inclined at angle ι' to horizontal, so that horizontal (dotted) lines through p', z bisect qe, ep'' at right angles respectively.
Also $S'' = 0$, as might have been foreseen, (Art. 575) since B'' is not loaded.

EXAMPLE 7.

Description.—A symmetrical Truss of 48' span with Rafters braced at their middles, the Tie-rod braced to inclination ι'.

Conditions and *Notation* (*see* Arts. 577, 578, 597) —W = 30,000 lbs., W' = 9,000 lbs.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 22 (*a*). Stress-diagram, *Fig.* 22 (*b*).

STEP I. *Polygon of Loads,* $a''b''c''c'b'a'ma''$ as in Ex. 4.

STEP II. *Resolution of Loads at joints.*—The Polygons of Forces for the joints taken in succession are

$b'a'mp'b'$ for joint A' ;	$ma''b''p''m$ for joint A''.
$c'b'p'q'c'$ for joint B' ;	$p''b''c''q''p''$ for joint B''.
$q'p'mhq'$ for joint M' ;	$mp''q''hm$ for joint M''.
$c''c'q'hq''c''$ for joint V.	

General Formulæ.

$$T_2' = p'b' = mb' \cdot \frac{\sin p'mb'}{\sin mp'b'} = \frac{3W}{8} \cdot \frac{\sin (90 + i')}{\sin (i - i')} = \frac{3W}{8} \cdot \cos i' \cdot \operatorname{cosec} (i - i'), \ (\textit{Thrust}).$$

$$H' = mp' = mb' \cdot \frac{\sin mb'p'}{\sin mp'b'} = \frac{3W}{8} \cdot \frac{\sin (90 - i)}{\sin (i - i')} = \frac{3W}{8} \cdot \cos i \cdot \operatorname{cosec} (i - i'), \ (\textit{Tension}).$$

$$S' = p'q' = q'e' \cdot \cos p'q'e' = c'b' \cdot \cos i = \frac{W}{4} \cos i, \ (\textit{Thrust}).$$

$$T_1' = q'c' = e'b' = p'b' - p'e' = p'b' - q'e' \cdot \sin p'q'e'$$

$$= T_2' - c'b' \cdot \sin i = T_2' - \frac{W}{4} \cdot \sin i, \ (\textit{Thrust}).$$

$$s' = hq' = q'o \cdot \frac{\sin hoq'}{\sin q'ho} = (q'c' - oc') \cdot \frac{\sin i}{\sin (2i - i')} = \left(T_1' - \frac{W}{8} \cdot \operatorname{cosec} i\right) \cdot \frac{\sin i}{\sin (2i - i')}$$

$$= \left(T_1' \sin i - \frac{W}{8}\right) \cdot \operatorname{cosec} (2i - i'), \ (\textit{Tension}).$$

$$H = mh = mn - nh = b'c' \cdot \cos mbb' - q'h \cdot \cos q'hn$$

$$T_1' \cdot \cos i - s' \cdot \cos (2i - i'), \ (\textit{Tension}).$$

Also evidently $T_1' = T_1''$; $T_2' = T_2''$; $S' = S''$; $s' = s''$; $H' = H''$.

Construction for *Normal Load.*

Frame-diagram, *Fig.* 22 (*c*). Stress-diagram, *Fig.* 22 (*d*).

STEP I. *Polygon of Loads,* $a''b''b'a'za''$ as in Ex. 4.

STEP II. *Resolution of Loads at joints.*—The Polygons of forces for the joints taken in succession are

$b'a'zp'b'$ for joint A' ;	$za''p''z$ for joint A''.
$b''b'p'qb''$ for joint B' ;	$p''a''p''$ for joint B'' (not loaded).
$qp'zhq$ for joint M' ;	$hzp''h$ for joint M''.
$a''b''qhp''a''$ for joint V.	

General Formulæ.

$$T_2' = p'b' = zb' \cdot \cot zp'b' = \left(R' - \frac{W'}{4}\right) \cdot \cot (i - i'), \ (\textit{Thrust}).$$

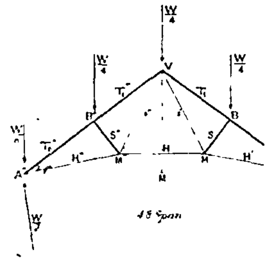
$$H' = zp' = zb' \operatorname{cosec} zp'b' = \left(R' - \frac{W'}{4}\right) \cdot \operatorname{cosec} (i - i'), \ (\textit{Tension}).$$

$$S' = qp' = b''b' = \frac{W'}{2}, \ (\textit{Thrust}).$$

$$T_1'' = T_2'' = p''a'' = a''z \cdot \frac{\sin p''za''}{\sin a''p''z} = R'' \cdot \frac{\sin (90 + i + i')}{\sin (i - i')}$$

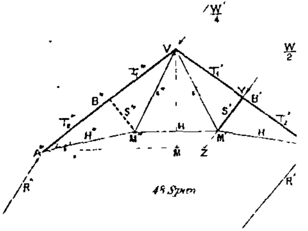
FRAME DIAGRAM.

Fig 22(a)



FRAME DIAGRAM

Fig 22(c)



$= R'' \frac{\cos(i + i')}{\sin(i - i')}$, (*Thrust*).

$S'' = 0$, *as might have been foreseen, (Art. 575), because B″ is unloaded.*

$H' = zp'' = a''z \cdot \frac{\sin za''p''}{\sin a''p''z} = R'' \cdot \frac{\sin(90 - 2i)}{\sin(i - i')} = R'' \cdot \frac{\cos 2i}{\sin(i - i')}$, (*Tension*).

$H = zh = zp'' \cdot \frac{\sin zp''h}{\sin zhp''} = H'' \cdot \frac{\sin 2(i - i')}{\sin(2i - i')} = 2R'' \cdot \frac{\cos 2i \cdot \cos(i - i')}{\sin(2i - i')}$, (*Tension*).

$s'' = hp'' = zp'' \cdot \frac{\sin hzp''}{\sin zhp''} = H'' \cdot \frac{\sin i'}{\sin(2i - i')}$, (*Tension*).

$s' = hq = he + eq = hp'' + \frac{qp'}{2} \cdot \sec eqp' = s'' + \frac{S'}{2} \operatorname{cosec}(i - i')$, (*Tension*).

Example 8.

Description.—A symmetrical Truss of 64′ span with Rafters braced by two Struts : the Rafters and Tie-rod (which is straight) are trisected by the bracing.

Conditions and *Notation* (*see* Arts. 577, 578, 597).—$W = 40{,}000$ lbs. $W' = 12{,}000$ lbs.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 23 (*a*). Stress-diagram, *Fig.* 23 (*b*).

STEP I. *Polygon of Loads.*—The Rafters being trisected, each segment bears $\frac{W}{6}$ so that the "Equivalent Loads at the joints" are

$$\frac{W}{12} \text{ at } A', A''; \frac{W}{6} \text{ at } B', C', V, C'', B''$$

The Re-actions are $\frac{W}{2}$ at A′ and A″.

$a''b''c''d''d'c'b'a'ma''$ *is the "Polygon of Loads".*

STEP II. *Resolution of Loads at the joints.*—The Polygons of Forces at the joints taken in succession are

$b'a'mpb'$ for joint A′; $ma''b''pm$ for joint A″.
$c'b'pq'c'$ for joint B′; $pb''c''q''p$ for joint B″.
$d'c'q'r'd'$ for joint C′; $q''c''d''r''q''$ for joint C″.
$r'q'pmNr'$ for joint M′; $Nmpq''r''N$ for joint M″.
$d''d'r'Nr''d''$ for joint V.

General Formulæ.

$T_1' = pb' = mb' \operatorname{cosec} mpb' = (md' + d'b') \cdot \operatorname{cosec} i = \frac{5W}{12} \operatorname{cosec} i$, (*Thrust*).

$H' = mp = mb' \cdot \cot mpb' = \frac{5W}{12} \cot i$, (*Tension*).

$\left.\begin{array}{l} T_2' = q'c' \\ T_3' = r'd' \end{array}\right\} = q''b' = d'b' \cdot \operatorname{cosec} d'q''b' = \frac{W}{3} \operatorname{cosec} i$, (*Thrust*).

$S_1' = pq' = nq' \cdot \operatorname{cosec} q'pn = d'm \cdot \operatorname{cosec} i = \frac{W}{12} \cdot \operatorname{cosec} i$, (*Thrust*).

$$S_2' = q'r' = c'd' = \frac{W}{6}, (\textit{Thrust}).$$

$$\left.\begin{aligned} S_1' = rN &= \sqrt{\overline{rn}^2 + \overline{nN}^2} = \sqrt{\overline{c''m}^2 + (q'n \cdot \cot q'Nn)^2} \\ &= \sqrt{\left(\frac{W}{4}\right)^2 + \left(\frac{W}{12} \cdot \cot i\right)^2} = \frac{W}{12} \cdot \sqrt{9 + \cot^2 i} \end{aligned}\right\}, (\textit{Tension}).$$

$$H = mN = mc' \cdot \cot mNc' = \left(\frac{W}{12} + \frac{W}{6}\right) \cdot \cot i = \frac{W}{4} \cot i, (\textit{Tension}).$$

Also $T_1' = T_1''$; $T_2' = T_2''$; $T_3' = T_3''$; $s_1' = s_1''$; $S_2' = S_2''$; $S_3' = S_3''$; $H' = H''$.

Construction for Normal Load.

Frame-diagram, *Fig.* 23 (*c*). Stress-diagram, *Fig.* 23 (*d*).

STEP I. *Polygon of Loads.*—The rafters being trisected, each segment of the rafter A'V bears $\frac{1}{3}$ of the whole Wind-pressure W', so that the Equivalent Loads at the joints are

$$\frac{W'}{6} \text{ at A' and V}; \ \frac{W'}{3} \text{ at B', and C'}.$$

The Re-actions are $R' = W'(1 - \frac{1}{4}\sec^2 i) = \frac{59}{84} W'$, $R'' = W' \cdot \frac{1}{4} \cdot \sec^2 i = \frac{25}{84} W'$, by Eq. (18), Art. 578 : also $a''b''mb'a'za''$ is the "Polygon of Loads".

STEP II. *Resolution of the Loads at the joints.*—The Polygon of forces at the joints taken in succession are—

$b'a'zp'b'$ for joint A'; $za''p''z$ for joint A''.
$mb'p'qm$ for joint B'; $p''a''p''$ for joint B'' (not loaded).
∴ The Bar B''M'' is not strained, and $S_3'' = 0$, also $T_3'' = T_2''$.
$b''mqrb''$ for joint C'; $p''a''p''$ for joint C'' (not loaded).
∴ The Bar C''M'' is not strained, and $S_2'' = 0$, also $T_2'' = T_1''$.
$rqp'zp''r$ for joint M'; $p''zp''$ for joint M''.
∴ The Bar M''V is not strained, and $S_1'' = 0$, also $H'' = H$.
$a''b''rp''a''$ for joint V.

N.B.—The Results $T_1'' = T_2'' = T_3''$, and $S_1'' = 0$, $S_2'' = 0$, $S_3'' = 0$, are the direct consequences of the joints B'', C'', M'' being *unloaded*: these Results might have been foreseen from the considerations given in Art. 575.

General Formulæ.

$$T_3' = p'b' = zb' \cdot \cot zp'b' = \left(R' - \frac{W'}{6}\right) \cdot \cot i, (\textit{Thrust}).$$

$$H' = zp' = zb' \cdot \operatorname{cosec} zp'b' = \left(R' - \frac{W'}{6}\right) \cdot \operatorname{cosec} i, (\textit{Tension}).$$

$$T_2' = qm = p'b' - p'n = p'b' - qn \cot qp'n = T_3' - \frac{W'}{3} \cdot \cot 2i, (\textit{Thrust}).$$

$$S_3' = p'q = qn \cdot \operatorname{cosec} qp'n = \frac{W'}{3} \cdot \operatorname{cosec} 2i, (\textit{Thrust}).$$

$$S_2' = qr = qN \cdot \sec Nqr = \frac{W'}{3} \cdot \sec i, (\textit{Thrust}).$$

$$T_1' = rb'' = rN + Nb'' = Nq \,.\, \tan Nrq + Nb'' = \frac{W'}{3} \,.\, \tan i + T'_2, \text{ (\textit{Thrust}).}$$

$$T_1'' = T_2'' = T_3'' = p''a'' = a''m \,.\, \operatorname{cosec} a''p''m = \frac{W'}{2} \,.\, \operatorname{cosec} 2\iota = \frac{W'}{4} \,.\, \operatorname{cosec} i \,.\, \sec i, \text{ (\textit{Thrust}).}$$

$$H = H'' = zp'' = zm \,.\, \operatorname{cosec} . \, zp''m = \left(R' - \frac{W'}{2}\right) . \operatorname{cosec} i, \text{ (\textit{Tension}).}$$

$$S_1' = p''r = p''o \,.\, \operatorname{cosec} p''ro = \frac{W'}{3} \,.\, \operatorname{cosec} M'VA' = \frac{W'}{3} \,.\, \operatorname{cosec}(\iota' - i), \text{ (\textit{Tension}).}$$

$$S_1'' = 0,\ S_2'' = 0,\ S_3'' = 0.$$

CALCULATION OF TOTAL "WORKING STRESS", *See* ARTS. 456, 596.

Bars.	Reference to *Fig* 23.	Stress.	Stresses[*] in pounds. Due to Vertl. Load.	Due to Wind: Greatest.	Due to Wind: Least.	Total "Working Stress" *in pounds.*	Character of Stress.
Rafters. Top-Segment,	VC′ or VC″	T_1' or T_1''	22,222 2/9	8,916 2/3	6,250	31,138 8/9	Thrust.
Rafters. Middle do,	C′B′ or C″B″	T_2' or T_2''	22,222 2/9	6,250	5,916 2/3	28,472 2/9	Thrust.
Rafters. Foot do,	B′A′ or B″A″	T_3' or T_3''	27,777 7/9	7,083 1/3	6,250	34,861 1/9	Thrust.
Tie-rod. Outer-segment,	M′A′ or M″A″	H′ or H″	22,222 2/9	8,854 2	2,187 1/2	31,076 4	Tension.
Tie-rod. Middle do.,	M′M″	H	13,333 1/3	2,187 1/2	2,187 1/2	15,520 5/6	Tension.
Braces, ..	VM′ or VM″	S_1' or S_1''	10,943 2	2,735 8	Nil.	13,679	Tension.
Struts, ..	C′M′ or C″M″	S_2' or S_2''	6,666 2/3	5,000	Nil.	11,666 2/3	Thrust.
Struts, ..	B′M′ or B″M″	S_3' or S_3''	5,555 5/9	4,166 2/3	Nil	9,722 2/9	Thrust.

Note.—The Working Stress" (Art. 596) = Stress due to Vertical Load + + Greatest Stress (of *same* character) due to Wind (from *either* side).

N B—Although *only the Greater of the two* Stresses due to Wind on either side of the Truss are required, (Art. 596) for Calculation of the Total "Working Stress", still it is *generally* necessary to calculate *both* Stresses numerically (or by measurement from the Stress-diagram if preferred) to ascertain *which* is the greater: *both* have accordingly been inserted in the above Table.

Calculation of Scantlings in Ex. 8.

It will be a useful exemplification of the principles of Chapters XXII. and XXIII. on Tension and Compression to calculate the scantlings for *one* complete Truss, *e.g.*, that of Example 8, in wrought-iron.

[*] The values given in the Table are by *calculation* from the formulæ, measurement from the scale would do equally well; the results by measurement will of course not be so exact, but this great exactness is unnecessary in practical Engineering (Art 597).

The scantlings are to be designed such as to bear the "Total " Working Stresses" calculated in the preceding Table.

N.B.—It must be remembered that the Rafters of this Truss were supposed, (*see* Art. 597), to be Loaded by Purlins applied *only at the joints* so that are there no Stresses included due to Transverse Strain.

Cross-sections and *Factors of Safety.*

Bars in Tension.—Round Rod-iron is a convenient form for all rods in Tension $s = 4$ (Art. 481).

Rafters.—T-iron with the head outwards is a very convenient form, as the Purlins rest on the flat head to which they are easily fastened. $s = 4$ (Art. 504).

Struts.—A pair of angle-irons placed back to back (⅂ ⅃) is a convenient form, as they thus embrace the shank of the T-iron rafter, and also the Tie-rod at the joints (which should be flattened for the purpose) in such a manner that the Resultant Stress is approximately symmetrically situate within the compound Strut, (*see* Art. 526—(6) as to the advisability of this arrangement). As the Stress is not, however, even, thus really uniformly distributed, it is advisable to make the factor of safety, higher than for the Rafters (Arts. 504, 526—(6), say $s = 5$).

Moduli of Strength.—$f_t = 60{,}000$; $f_c = 36{,}000$, (Appendix II).

Calculation of Scantlings.

Notation, Art. 481, 504.—Observe that in what follows W is the "Working Load" (Tensile or Crushing) or " Working Stress" on *each* Bar in succession as required in the formulæ of Chaps. XXII , XXIII ; this must not be confused with the W used for Working Load on the whole Truss.

Bars in Tension.—These are easily designed ; for being of round iron, $A = \frac{\pi}{4} d^2$, also $f_t A = sW$ (Eq 1 and 2, Art. 481),

$$\therefore d = \sqrt{\frac{4}{\pi} \cdot \frac{sW}{f_c}} = \sqrt{\frac{7 \times 4 \times 4W}{22 \times 60000}} = \sqrt{\frac{14W}{11 \times 15000}}$$

where W is the "Total Working Stress".

Taking this from the Table of Total Working Stresses, we have

Tie-rod, Outer-segment, $W = 31{,}076$, $\therefore d = 1{\cdot}6$ inches, say $1\frac{5}{8}$ inches.
Tie-rod, Middle-segment, $W = 15{,}520$, $\therefore d = 1{\cdot}14$ inches, say $1\frac{1}{8}$ inches.
Braces, $W = 13{,}679$, $\therefore d = 1{\cdot}08$ inches, say 1 inch.

N.B.—It must be *carefully* borne in mind that the diameter (d) or breadth of ties thus found, is the diameter of *net* area A of cross-section of each bar, (*i. e.*, of area of *Solid* metal *left* after deducting all rivet-and bolt-holes, (*see* Art 481).

Morever the *joints* at the ends of the ties should be so arranged that the resultant Stress passes down the axis of each Bar, (*see* Art. 482,) *otherwise* the Ties must be made *thicker* than as just calculated.

Rafter VA′ *or* VA″.—It is convenient for *constructive* reasons to make the Rafter *in one piece* and *of uniform section* throughout : it must of course be designed to bear the *greatest* thrust on *any* part of it, (viz., that on its lowest segment B′A′ or B″A″), which is 34,861½ lbs. The waste of iron by making the two upper segments of same scantling as the lower (which has to bear the greatest stress) is *very small,* *see* Table of "Working Stresses ".

The Rafter may be designed as a "Pillar" of length = $\frac{1}{3}$ Length of Rafter = $\frac{l}{3}$, and with "both ends fixed", *provided care be taken* that the riveting (Art. 511) at the Ridge, Wall-plates, and Strut heads is sufficient to make *all* the joints *very stiff* (as can *generally* be arranged in such a large Truss as the present).

The details of this arrangement fall properly under the head of "Joints".

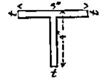
As in the figure of cross-section (T-iron) chosen, there are *four* quantities, (viz, breadth, depth, and two thicknesses to be determined, and *only one* equation of condition, (viz., Working Stress = Working Resistance), three conditions must be assumed between b, d, t, (*see* Art. 521—(3)). it will be convenient to assume values for b, d for reasons explained in Art. 521.

As some guide in assuming b, d, observe that the cross-section must clearly contain *more* iron than if designed as for a "Short Pillar", on which supposition (by Eq (2), Art. 507), $A = sW \div f_c = 4 \times 3{,}4861 \div 36{,}000 = 3{\cdot}87$ inches.

Assuming accordingly breadth of head = 5", depth of shank = 4", thickness of head and shank each = t, then

Whole Area $A = 5t + (4 - t)\,t = (9t - t^2)$ square inches.

Least width $d = 4''$, $l = 12\,L = \left(12 \times \frac{40}{3}\right)''$.



$\therefore$ By Gordon's formula Eq. (18), Art. 520,

$$sW = f_c\,A \,.\div \left\{1 + c\,.\left(\frac{l}{d}\right)^2\right\}$$

$$(9t - t^2) = A = sW\,.\left\{1 + c\left(\frac{l}{d}\right)^2\right\} \div f_c$$

$$= \frac{4 \times 34861}{36000}\left\{1 + \frac{1}{3000} \times \left(\frac{40 \times 12}{3 \times 4}\right)^2\right\}$$

$$= 3{\cdot}874\,.\left\{1 + \frac{8}{15}\right\} = 3{\cdot}874 \times 1{\cdot}53 = 5{\cdot}93.$$

Hence $t = {\cdot}72$ inches, nearly, or *say* $\frac{3}{4}$-inch.

Thus the Rafters may be made of $5'' \times 4'' \times \frac{3}{4}''$ T-iron

Struts—These are to be designed as "Pillars" of length C'M' or C"M" (= 16'), and B'M' or B"M" (= $13\frac{1}{3}$'), and with "both ends fixed," *provided care be taken* that the riveting (Art 511) at their ends be sufficient to make the joints *very stiff* (as can generally be arranged in such a large Truss as the present).

As in the cross section (a pair of angle-irons, thus ˥˹), chosen, there are several quantities, (viz, lengths and thickness of arms) to be determined, and only *one* equation of condition, (viz, Working Stress = Working Resistance), several conditions must be assumed between the quantities required (Art 521—(3)).

It is convenient (for constructive reasons) to choose the angle-irons alike, and of uniform thickness, also to choose the ratio between the arms as 1 : 2, so that when placed together, the breadth (b) and depth (d) of the compound Strut may be equal, *i. e*, $b = d$. It is convenient also (for reasons explained in Art. 521—3), to assume values for b, d, so that t may be the only undetermined quantity.

As some guide in assuming b, d, observe that the cross section must clearly contain *more* iron than if designed as for a "Short Pillar", on which supposition by Eq (2), Art. 507, the areas of iron required would be

For C'M' or C"M", $A = sW \div f_c = 5 \times 11666 \div 36{,}000 = 1\frac{1}{2}$ sq in., *nearly*.

For B'M' or B"M", $A = sW \div f_c = 5 \times 9722 \div 36{,}000 = 1\frac{1}{4}$ sq in, *nearly*.

The scantlings are to be designed such as to bear the "Total" Working Stresses" calculated in the preceding Table.

N.B.—It must be remembered that the Rafters of this Truss were supposed, (*see* Art. 597), to be Loaded by Purlins applied *only at the joints* so that are there no Stresses included due to Transverse Strain.

Cross-sections and *Factors of Safety.*

Bars in Tension.—Round Rod-iron is a convenient form for all rods in Tension $s = 4$ (Art. 481).

Rafters.—T-iron with the head outwards is a very convenient form, as the Purlins rest on the flat head to which they are easily fastened $s = 4$ (Art. 504).

Struts.—A pair of angle-irons placed back to back (┐┌) is a convenient form, as they thus embrace the shank of the T-iron rafter, and also the Tie-rod at the joints (which should be flattened for the purpose) in such a manner that the Resultant Stress is approximately symmetrically situate within the compound Strut, (*see* Art. 526—(6) as to the advisability of this arrangement). As the Stress is not, however, even, thus really uniformly distributed, it is advisable to make the factor of safety, higher than for the Rafters (Arts. 504, 526—(6), say $s = 5$).

Moduli of Strength.—$f_t = 60{,}000$, $f_c = 36{,}000$, (Appendix II).

Calculation of Scantlings.

Notation, Art. 481, 504.—Observe that in what follows W is the "Working Load" (Tensile or Crushing) or "Working Stress" on *each* Bar in succession as required in the formulæ of Chaps. XXII., XXIII; this must not be confused with the W used for Working Load on the whole Truss.

Bars in Tension.—These are easily designed; for being of round iron, $A = \frac{\pi}{4}d^2$, also $f_t A = sW$ (Eq. 1 and 2, Art. 481),

$$\therefore\ d = \sqrt{\frac{4}{\pi}\cdot\frac{sW}{f_c}} = \sqrt{\frac{7 \times 4 \times 4W}{22 \times 60000}} = \sqrt{\frac{14W}{11 \times 15000}}$$

where W is the "Total Working Stress".

Taking this from the Table of Total Working Stresses, we have

Tie-rod, Outer-segment, $W = 31{,}076$, $\therefore d = 1{\cdot}6$ inches, say $1\frac{3}{4}$ inches.
Tie-rod, Middle-segment, $W = 15{,}520$, $\therefore d = 1{\cdot}14$ inches, say $1\frac{1}{8}$ inches.
Braces, $W = 13{,}679$, $\therefore d = 1{\cdot}08$ inches, say 1 inch.

N.B.—It must be *carefully* borne in mind that the diameter (d) or breadth of ties thus found, is the diameter of *net* area A of cross-section of each bar, (*i. e.*, of area of *Solid* metal *left* after deducting all rivet-and bolt-holes, (*see* Art. 481).

Moreover the *joints* at the ends of the ties should be so arranged that the resultant Stress passes down the axis of each Bar, (*see* Art. 482,) *otherwise* the Ties must be made *thicker* than as just calculated.

Rafter VA′ or VA″.—It is convenient for *constructive* reasons to make the Rafter *in one piece* and *of uniform section* throughout: it must of course be designed to bear the *greatest* thrust on *any* part of it, (viz., that on its lowest segment B′A′ or B″A″), which is 31,861½ lbs. The waste of iron by making the two upper segments of same scantling as the lower (which has to bear the greatest stress) is *very small*, *see* Table of "Working Stresses".

The Rafter may be designed as a "Pillar" of length = ⅓ Length of Rafter $= \frac{l}{3}$, and with "both ends fixed", *provided care be taken* that the riveting (Art. 511) at the Ridge, Wall-plates, and Strut heads is sufficient to make *all* the joints *very stiff* (as can *generally* be arranged in such a large Truss as the present).

The details of this arrangement fall properly under the head of "Joints".

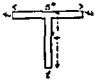
As in the figure of cross-section (T-iron) chosen, there are *four* quantities, (viz., breadth, depth, and two thicknesses to be determined, and *only one* equation of condition, (viz., Working Stress = Working Resistance), three conditions must be assumed between b, d, t, (*see* Art. 521—(3)) : it will be convenient to assume values for b, d for reasons explained in Art. 521.

As some guide in assuming b, d, observe that the cross-section must clearly contain, *more* iron than if designed as for a "Short Pillar", on which supposition (by Eq (2), Art 507), $A = sW \div f_c = 4 \times 3{,}4861 \div 36{,}000 = 3\ 87$ inches.

Assuming accordingly breadth of head = 5", depth of shank = 4", thickness of head and shank each = t, then

Whole Area $A = 5t + (4 - t)\,t = (9t - t^2)$ square inches.

Least width $d = 4''$, $l = 12\ L = \left(12 \times \frac{40}{3}\right)''$.



∴ By Gordon's formula Eq. (18), Art. 520,

$$sW = f_c\,A \,.\, \div \left\{1 + c\,\left(\frac{l}{d}\right)^2\right\}$$

$$(9t - t^2) = A = sW \,.\, \left\{1 + c\left(\frac{l}{d}\right)^2\right\} \div f_c$$

$$= \frac{4 \times 34861}{36000}\left\{1 + \frac{1}{3000} \times \left(\frac{40 \times 12}{3 \times 4}\right)^2\right\}$$

$$= 3\ 874\ \left\{1 + \frac{8}{15}\right\} = 3\ 874 \times 1\ 53 = 5\ 93.$$

Hence t = 72 inches, nearly, or *say* ¾-inch.

Thus the Rafters may be made of 5" × 4" × ¾" T-iron

Struts.—These are to be designed as "Pillars" of length CM or C'M' (= 16'), *and* BM' or B"M" (= 13⅓'), *and with "both ends fixed," provided care be taken* that the riveting (Art. 511) at their ends be sufficient to make the joints *very stiff* (as can generally be arranged in such a large Truss as the present)

As in the cross section (a pair of angle-irons, thus ⌉⌈), chosen, there are several quantities, (viz., lengths and thickness of arms) to be determined, and only *one* equation of condition, (viz., Working Stress = Working Resistance), several conditions must be assumed between the quantities required (Art. 521—(3))

It is convenient (for constructive reasons) to choose the angle-irons alike and of uniform thickness, also to choose the ratio between the arms as 1 : 2, so that when placed together, the breadth (b) and depth (d) of the compound Strut may be equal, *i.e.*, $b = d$. It is convenient also (for reasons explained in Art. 521—3), to assume values for b, d, so that t may be the only undetermined quantity

As some guide in assuming b, d, observe that the cross-section must clearly contain *more* iron than if designed as for a "Short Pillar", on which supposition (by Eq. (2), Art. 507, the areas of iron required would be

For CM or C'M', $A = sW \div f_c = 5 \times$ [illegible] $=$ [illegible] $= 1\frac{1}{2}$ [illegible] *nearly*

For BM or B'M', $A = sW \div f_c = 5 \times$ [illegible] $=$ [illegible] $= 1\frac{1}{2}$ [illegible] *nearly*

As the Total Areas of iron required are so nearly alike for both pairs of Struts, it would be preferable (for simplicity of construction) to make them all alike, and, therefore, all like C'M' or C"M", (which must have greater scantlings than B'M' or B"M", as they have to bear the greater Stress, and are, moreover, of greater clear length (L)).

Assuming the arms of the angle-irons as 3 inches and $1\frac{1}{2}$ inches, *i. e*,

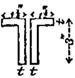
$$d = 3'', \ b = 1\tfrac{1}{2}'' + 1\tfrac{1}{2}'' = 3'', \ A = 2 \times \left\{1\tfrac{1}{2}'' \times t + t\,(3 - t)\right\} = 9t - 2t^2.$$

Hence by Gordon's formula Eq. (18), Art. 520.

$$9t - 2t^2 = A = \frac{sW}{f_c} \cdot \left\{1 + c \cdot \left(\frac{12\,L}{d}\right)^2\right\}$$

$$= \frac{5 \times 11666}{36000} \cdot \left\{1 + \frac{144 \times 256}{3000 \times 9}\right\}$$

$$= \frac{5833}{3600} \times 2\cdot365 = 3\cdot83 \text{ square inches.}$$



$$\therefore \ t = \tfrac{1}{2} \text{ inch, nearly.}$$

Hence all the Struts may be made of a pair, each of $3'' \times 1\frac{1}{2}'' \times \frac{1}{2}''$ inch angle-iron.

Example 9.

Description.—A symmetrical Truss of 64' span with Rafters braced by two Struts : the Rafters and Tie-rod (which is straight), are trisected by the bracing.

Conditions and *Notation* (*see* Arts. 577, 578, 597).—W = 40,000 lbs., W' = 12,000 lbs.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 24 (*a*). Stress-diagram, *Fig.* 24 (*b*).

STEP I.—*Polygon of Loads*, $a''b''c''d''d'c'b'a'ma''$, as in Ex. 8.

STEP II.—*Resolution of Loads at the joints.*—The Polygons of Forces at the joints taken in succession are

$b'a'mpb'$ for joint A' ;	$ma''b''pma''$ for joint A".
$c'b'pq'c'$ for joint B' ;	$pb''c''q''p$ for joint B".
$q'pmnq'$ for joint M' ;	$mpq''nm$ for joint M".
$d'c'q'nr'd'$ for joint C' ;	$nq''c''d''r''n$ for joint C".
$r'nmnr''r'$ for joint M.	
$d''d'r'r''d''$ for joint V.	

General Formulæ.

$$T_1' = pb' = mb' \operatorname{cosec} mpb' = \frac{5W}{12} \operatorname{cosec} i, \ (\textit{Thrust}).$$

$$H_1' = mp = mb' \cdot \cot mpb' = \frac{5W}{12} \cot i, \ (\textit{Tension}).$$

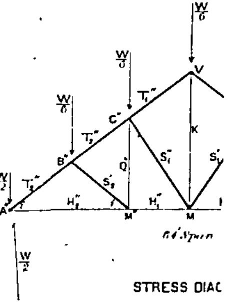
$$Q' = q'n = \tfrac{1}{2} q'q'' = \tfrac{1}{2} c'b' = \frac{W}{12}, \ (\textit{Tension}).$$

$$S_1' = pq' = q'n \operatorname{cosec} q'pm = \frac{W}{12} \cdot \operatorname{cosec} i, \ (\textit{Thrust}).$$

$$K = r'r'' = d'c' + c''d'' = \frac{W}{3}, \ (\textit{Tension}).$$

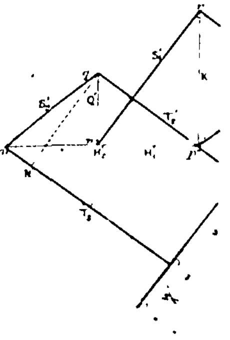
FRAME DIAGF

Fig 24(a)



STRESS DIAC

Fig 24(b



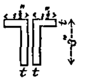
As the Total Areas of iron required are so nearly alike for both pairs of Struts, it would be preferable (for simplicity of construction) to make them all alike, and, therefore, all like C'M' or C"M", (which must have greater scantlings than B'M' or B"M", as they have to bear the greater Stress, and are, moreover, of greater clear length (L)).

Assuming the arms of the angle-irons as 3 inches and $1\frac{1}{2}$ inches, *i. e*,

$$d = 3'', \; b = 1\tfrac{1}{2}'' + 1\tfrac{1}{2}'' = 3'', \; A = 2 \times \{1\tfrac{1}{2}'' \times t + t(3 - t)\} = 9t - 2t^2.$$

Hence by Gordon's formula Eq. (18), Art. 520.

$$9t - 2t^2 = A = \frac{sW}{f_c} \cdot \left\{1 + c \cdot \left(\frac{12\,L}{d}\right)^2\right\}$$
$$= \frac{5 \times 11666}{36000} \cdot \left\{1 + \frac{144 \times 256}{3000 \times 9}\right\}$$
$$= \frac{5833}{3600} \times 2.365 = 3.83 \text{ square inches.}$$



$\therefore\; t = \frac{1}{2}$ inch, nearly.

Hence all the Struts may be made of a pair, each of $3'' \times 1\frac{1}{2}'' \times \frac{1}{2}''$ inch angle-iron.

Example 9.

Description.—A symmetrical Truss of 64′ span with Rafters braced by two Struts: the Rafters and Tie-rod (which is straight), are trisected by the bracing.

Conditions and *Notation* (*see* Arts. 577, 578, 597).—$W = 40{,}000$ lbs., $W' = 12{,}000$ lbs.

Construction for Vertical Load.

Frame-diagram, *Fig*. 24 (*a*). Stress-diagram, *Fig*. 24 (*b*).

STEP I.—*Polygon of Loads*, $a''b''c''d''d'c'b'a'ma''$, as in Ex. 8.

STEP II.—*Resolution of Loads at the joints.*—The Polygons of Forces at the joints taken in succession are

$b'a'mpb'$ for joint A′;	$ma''b''pma''$ for joint A″.
$c'b'pq'c'$ for joint B′;	$pb''c''q''p$ for joint B″.
$q'pmnq'$ for joint M′;	$mpq''nm$ for joint M″.
$d'c'q'nr'd'$ for joint C′;	$nq''c''d''r''n$ for joint C″.
$r'nmnr''r'$ for joint M.	
$d''d'r'r''d''$ for joint V.	

General Formulæ.

$$T_3' = pb' = mb' \operatorname{cosec} mpb' = \frac{5W}{12} \operatorname{cosec} i, \; (\textit{Thrust}).$$

$$H_1' = mp = mb' \cdot \cot mpb' = \frac{5W}{12} \cot i, \; (\textit{Tension}).$$

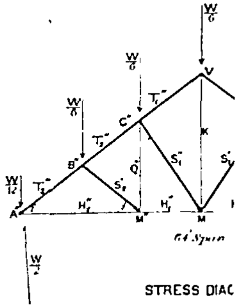
$$Q' = q'n = \tfrac{1}{2} q'q'' = \tfrac{1}{2} c'b' = \frac{W}{12}, \; (\textit{Tension}).$$

$$S_1' = pq' = q'n \operatorname{cosec} q'pm = \frac{W}{12} \cdot \operatorname{cosec} i, \; (\textit{Thrust}).$$

$$K = r'r'' = d'c' + c''d'' = \frac{W}{3}, \; (\textit{Tension}).$$

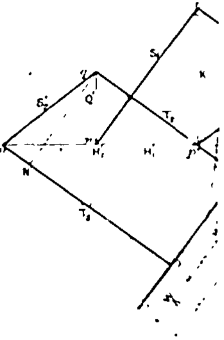
FRAME DIAGF

Fig 24(a)



STRESS DIAC

Fig 24(b



$$T_1' = q'c' = pb' - pq'' = T_2' - S_1'' = \frac{W}{3} \operatorname{cosec} i, \textit{ (Thrust).}$$

$$T_1' = r'd' = pb' - pr'' = T_2' - 2\, S_1'' = \frac{W}{4} \operatorname{cosec} i, \textit{ (Thrust)}$$

$$H_1' = mn = q''b''. \cos i, = T_1'. \cos i = \frac{W}{8}. \cot i, \textit{ (Tension).}$$

$$S_1' = nr' = \sqrt{nN^2 + r'N^2} = \sqrt{(q'n . \cot q'Nn)^2 + d'c'^2}$$

$$= \sqrt{\left(\frac{W}{12} \cot i\right)^2 + \frac{W}{6}} = \frac{W}{12} \sqrt{4 + \cot^2 i}, \textit{ (Thrust).}$$

Construction for Normal Load.

Frame-diagram, *Fig.* 24 (*c*). Stress-diagram, *Fig.* 24 (*d*).

STEP I.—*Polygon of Loads*, $a''b''mb'a'za''$, as in Ex. 8.

STEP II.—*Resolution of the Loads at the joints.*—The Polygons of Forces for the joints taken in succession are

$b'a'zp'b'$ for joint A' ;	$za''p''z$ for joint A''.
$mb'p'qm$ for joint B' ;	$p''a''p''$ for joint B'' (unloaded).
$qp'znq$ for joint M' ;	$zp''z$ for joint M'' (unloaded).
$b''mqnrb''$ for joint C' ;	$p''a''p''$ for joint C'' (unloaded).
$rnzp''r$ for joint M (unloaded).	
$a''b''rp''a''$ for joint V.	

N.B.—The Bars B''M'', M''C'', C''M, are seen from the construction of the polygons e *unstrained.*

$S_1'' = 0$, $Q'' = 0$, $S_1'' = 0$, so $T_1'' = T_2'' = T_3''$, and $H_1'' = H_2''$ — as might have been anticipated, in consequence of the joints B'', M'', C'' being unloaded *see* Art. 575.

General Formulæ.

$$= p'b' = zb' \cot zp'b' = \left(R' - \frac{W'}{6}\right) . \cot i, \textit{ (Thrust).}$$

$$' = zp' = zb' . \operatorname{cosec} zp'b' = \left(R' - \frac{W'}{6}\right) . \operatorname{cosec} i, \textit{ (Tension).}$$

$$_2' = p'q = qN . \operatorname{cosec} qp'N = mb' . \operatorname{cosec} 2\, i = \frac{W'}{3} . \operatorname{cosec} 2\, i, \textit{ (Thrust).}$$

$$_2' = qm = p'b' - p'N = p\,b' - qN . \cot qp'N = T_2' - \frac{W'}{3} . \cot 2\, i, \textit{ (Thrust).}$$

$$= nq = p'q . \sin qp'n = S_2' . \sin i = \frac{W'}{6} \sec i, \textit{ (Tension).}$$

$$= T_2'' = T_3'' = p''a'' = a''m . \operatorname{cosec} a''p''m = \frac{W'}{2} . \operatorname{cosec} 2\, i, \textit{ (Thrust).}$$

$$= H_2'' = zp'' = zm . \operatorname{cosec} zp''m = \left(R' - \frac{W'}{2}\right) \operatorname{cosec} i, \textit{ (Tension).}$$

$$rp'' = p''e . \sec rp''e = mb'' . \sec rp''e = \frac{W'}{3} . \sec i, \textit{ (Tension)}$$

$H_1' = zn = zp' - p'n = zp' - qp'.\cos i = H_2'' - S_2'.\cos i = \left(R' - \frac{W'}{3}\right).\operatorname{cosec} i$, (*Tension*).

$S_1' = \sqrt{rp''^2 + np''^2} = \sqrt{rp''^2 + (zn - zp'')^2} = \sqrt{K^2 + (H_1' - H_1'')^2} =$

$= \sqrt{K^2 + \left(\frac{W'}{6}\operatorname{cosec} i\right)^2} = \frac{W'}{6}\sqrt{4\sec^2 i + \operatorname{cosec}^2 i}$, (*Thrust*).

$T_1' = rb'' = re + p''m = p''e.\tan rp''e + mz\cot zp''m = \frac{W'}{3}.\tan i + \left(R' - \frac{W'}{2}\right)\cot i$, (*Thrust*).

$S_2'' = 0,\ Q'' = 0,\ S_1'' = 0.$

Example 10.

Description.—A symmetrical Queen-post Truss of 64′ span, with Rafters trisected by the bracing.

Conditions and *Notation* (*see* Arts. 577, 578, 597).—$W = 40{,}000$ lbs., $w = 1{,}000$ lbs., $w' = 2{,}000$ lbs., $W' = 12{,}000$ lbs.

This Truss is the same and under the same Load as in Ex. 2 of Method i.

Construction for *Vertical Load.*

Frame-diagram, *Fig.* 25 (*a*). Stress-diagram, *Fig.* 25 (*b*).

Step I. *Polygon of Loads.*—The "Equivalent Loads at the joints" are as in Ex. 8, except that owing to the addition of the Loads w on the Ridge, and w' at foot of each of the Queen-rods, the Equivalent Loads at these points are $\left(\frac{W}{6} + w\right)$ at V, and w' at M′ and M″.

Also the Re-actions are $\left(\frac{W+w}{2} + w'\right)$ at A′, A″.

Taking separate Load-lines (as directed in Ex. 5) for the Loads on Rafters and Tie-rods, it follows that (the lines $a''a''$, $a'a'$ overlapping)

$a''b''c''d''d'c'b'a'a'a''a''$ is the Polygon of Loads.

Step II. *Resolution of Loads at the joints.*—The Polygons of forces at the joint taken in succession are

$b'a'a'p'b'$ for joint A′;	$a''a''b''p''a''$ for joint A″.
$c'b'p'q'c'$ for joint B′;	$p''b''c''q''p''$ for joint B″.
$q'p'a'mnq'$ for joint M′;	$nma''p''q''n$ for joint M″.
$d'c'q'nNd'$ for joint C′;	$q''c''d''Nnq''$ for joint C″.
$d''d'Nd''$ for joint V.	

General Formulæ.

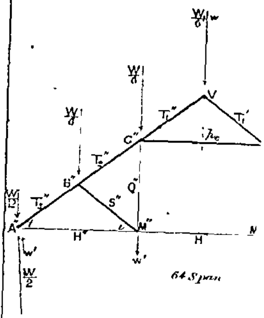
$T_3' = p'b' = b'a'.\operatorname{cosec} b'p'a' = (b'm + ma').\operatorname{cosec} i.$

$= \left\{\frac{W}{6} + \frac{W}{6} + \frac{1}{2}.\left(\frac{W}{6} + w\right) + w'\right\}\operatorname{cosec} i = \left(\frac{5W}{12} + \frac{w}{2} + w'\right).\operatorname{cosec} i$, (*Thrust*).

$H' = a'p' = b'a'.\cot b'p'a' = \left(\frac{5W}{12} + \frac{w}{2} + w'\right).\cot i$, (*Tension*).

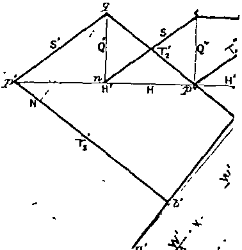
FRAME DIAGRAM.

Fig. 25.(a)



STRESS DIAG

Fig 25(d)



This might of course be done in many ways: the simplest way appears to be to add the Bars C′M″, C″M′, to divide the open quadrilateral into triangles (the only form which with "free joints" can resist Load distributed in any manner whatever).

N.B.—One only of the Bars C′M′, C″M″ is *essential* to equilibrium, but it is usual to add both for the sake of symmetry: but even then, *one* only of these bars is relied on for resisting the Wind as blowing from the *right*, and *the other* for resisting Wind from the *left*, so that in *drawing* the Stress-diagram for Wind from the *right* as in figure, one bar is neglected; and similarly if a special Stress-diagram be drawn for Wind from the *left*, the other bar would be neglected. But there is a further *analytical* reason for introducing *only one* of these bars at a time, viz, to avoid the difficulty of the "Indeterminate Problem" (explained in Art. 576, *q. v.*), which would be introduced, as will be seen on actual trial, *see* below.

It is optional which Bar shall be introduced on each occasion. In the Frame-diagram (*Fig* 25 (*c*)) for Wind from the *right*, the bar C′M″ is introduced; and C″M′ will be considered as introduced solely for resisting Wind from the *left*.

Stress-diagram construction.—The bar C′M″ having been added, there will now be *no difficulty* in drawing the Stress-diagram (*Fig.* 25 (*d*)). The Polygons of Forces at the joints taken in succession are

$b'a'zp'b'$ at joint A′; $za''p''z$ at joint A″.
$mb'p'qm$ at joint B′; $p''a''p''$ at joint B″, (unloaded).
$qp'znq$ at joint M′; $nzp''en$ at joint M″.

N.B.—Had the bar C″M′ been included (as well as C′M″) in the Frame, then at the joint M′ there would have been more than two unknown Stresses, viz, those on the bars M′M″, M′C″, M′C′ to determine, a problem which has been explained to be *indeterminate* (Art. 576): nor could this difficulty be avoided by taking the joints in any other order. The remaining polygons are

$b''mqnerb''$ for joint C′; $rep''a''r$ for joint C″, (unloaded).
$a''b''ra''$ for joint V.

The check on the work is obvious.

Note.—With Wind blowing from the *left*, the Bar C″M′ is introduced and C′M″ is omitted for reasons above explained; the Stress on the Bar C″M′ will from the symmetry of the figure clearly be *the same* as that on C′M″ under Wind from the *right*. Both these bars will thus be found to be *in compression*: if interchanged, they would be found (by constructing new Stress-diagrams) *in tension*.

General Formulæ.

$$\mathrm{T}_1' = p'b' = zb'\,.\cot zp'b' = \left(\mathrm{R}' - \frac{\mathrm{W}'}{6}\right).\cot i,\ (\textit{Thrust}).$$

$$\mathrm{R}' = zp' = zb'\,.\operatorname{cosec} zpb' = \left(\mathrm{R}' - \frac{\mathrm{W}'}{6}\right).\operatorname{cosec} i,\ (\textit{Tension}).$$

$$\mathrm{S}' = p'q = q\mathrm{N}\,.\operatorname{cosec} qp'\mathrm{N} = \frac{\mathrm{W}'}{3}\,.\operatorname{cosec} 2i,\ (\textit{Thrust}).$$

$$\mathrm{Q} = qn = p'q\,.\sin qp'n = \mathrm{S}'\,.\sin i = \frac{\mathrm{W}'}{6}\,.\sec i,\ (\textit{Tension}).$$

$$\mathrm{T}_1'' = \mathrm{T}_2'' = p''a'' = a''m\,.\operatorname{cosec} a''p''m = \frac{\mathrm{W}'}{2}\,.\operatorname{cosec} 2i,\ (\textit{Thrust})$$

$$T_1'' = ra'' = a''b''.\operatorname{cosec} a''rb'' = \frac{W'}{6}.\operatorname{cosec} 2i, \text{ (*Thrust*).}$$

$$T_1' = rb'' = a''b''.\cot a''rb'' = \frac{W'}{6}.\cot 2i, \text{ (*Thrust*).}$$

$$H = sn = sp' - p'n = H' - S'.\cos i = \left(R' - \frac{W'}{3}\right)\operatorname{cosec} i, \text{ (*Tension*).}$$

$$H'' = sp'' = sm \operatorname{cosec} sp''m = \left(R' - \frac{W'}{2}\right).\operatorname{cosec} i, \text{ (*Tension*).}$$

$$S = S', S'' = 0, Q'' = Q'.$$

$$h_e = er = ep''.\cot erp'' = Q''.\cot i = \frac{W'}{6}\operatorname{cosec} i, \text{ (*Thrust*).}$$

Caution to Students.

The following mistake is very frequently made by beginners in finding the Stresses in Trusses by Method i, (Method of Resolution).

Take the simple case of the simplest Truss, *Fig.* 16 (*a*) :—Having ascertained the "Equivalent Load" on the vertex (V) to be $\frac{W}{2}$, they proceed to say that

"The Stress down VA' or VA" *produced by* $\frac{W}{2}$ is clearly (?) equal to the resolved part of $\frac{W}{2}$ in those directions, *i. e.*, to $\frac{W}{2}$ sin i". Now this is only *partly* true, *i. e.*, $\frac{W}{2}$ sin *i* is only a part of the Stress produced by the Load $\frac{W}{2}$: it ought to be evident, from mere inspection, that the "Direct Resistances" of the rafters A'V, A"V at the point V must *necessarily* be both greater than $\frac{W}{2}$, because *neither* of them *directly* oppose the Load $\frac{W}{2}$, whereas the result $\frac{W}{2}$ sin *i* obtained above, is less than $\frac{W}{2}$ (because sin *i* is necessarily < 1).

The fact is, that the Direct Resistances of A'V, A"V at V must be exactly so much *greater than* the (Vertical) Load $\frac{W}{2}$, that the sum of *their* vertically resolved parts shall balance $\frac{W}{2}$, *i. e.*,

$$T' \cos A'VH + T'' \cos A''VH = (T' + T'') \sin i = \frac{W}{2} \text{ .... (i).}$$

But inasmuch as their horizontally resolved parts must balance each other to maintain equilibrium at V,

$$T' \sin A'VH = T'' \sin A''VH, \text{ whence } T' = T'' \text{ .... (ii).}$$

$$\text{Hence from (i), } T' = \frac{W}{4}\operatorname{cosec} i = T'' \text{ .... (iii).}$$

Observe that this result is the same as obtained in Ex. (1) of Method ii.

The mistake alluded to can never occur in use of any graphic method (this is one

great advantage of Method ii), nor can it occur if the particular train of reasoning adopted in this Treatise (*see* Art 582—(1) and (4), also just stated above) be invariably followed, when using the "Method of Resolution" (Method i) viz., of deducing T′, T″ from the fundamental equations of equalibrium, *i. e*,

$$\left.\begin{array}{l}\text{Sum of vertically resolved parts of}\\ \quad\text{the Stresses } T', T'',\end{array}\right\} = \text{Vertical Load, } \ldots\ldots\ldots\ldots\ldots\ldots \text{(i).}$$

$$\begin{array}{l}\text{Sum of horizontally resolved parts}\\ \quad\text{of the Stresses } T', T'',\end{array}\left\{\begin{array}{l}= \text{Horizontal Load (if any)}\\ = 0, \text{ if there is no horizontal Load.}\end{array}\right\}\ldots\ldots\text{(ii).}$$

Any method of equating resolved parts without *distinctly* expressing the conditions of equilibrium is *very liable to error*. In graphic methods these conditions are satisfied by the act of construction, which (when complete) generally renders errors evident to the eye.

Note to Method ii.—This method styled in this Treatise the "Polygonal Method" is due to Professor Clerk-Maxwell; it is hence sometimes described "as Clerk-Maxwell's Method."

The germ of this Method is contained in the following proposition in Rankine's Applied Mechanics (Art. 150), viz ,

"If lines radiating from a point be drawn parallel to the lines of resistance of the "bars of a polygonal frame, then the sides of any polygon whose angles lie in those "radiators represent a system of forces, which, being applied to the joints of the frame, "will balance each other, each force being applied to the joint between the bars which "are parallel to the pair of radiators that enclose the side (of the polygon of forces) "representing that force. Also the lengths of those radiators represent the stresses "along the bars to which they are parallel."

CHAPTER XXVI.

TRANSVERSE STRAIN.

Preface.—This Chapter also has been re-written,* but in consequence of the very urgent demand for the Treatise, its scope has been limited nearly to that of the similar Chapters (XI. and XII.) of the last (2nd) Edition, viz., to the simple formulæ for Breaking Weight, and to Barlow's simple deflexion-formulæ. The subject of Transverse strain generally, will be continued† in the 3rd Edition of the 2nd Volume.

598. **Transverse Strain.**—Any piece of material loaded transversely, *i. e.*, in which the Re-actions of the supports do not *directly* oppose the Load, is said to be "strained transversely", or to be under TRANSVERSE STRAIN.

599. **Beam, Girder, Cantilever.**—Any piece of material under Transverse Strain is called *in general* a BEAM: a large or composite Beam is often called a GIRDER. A Beam firmly fixed to one support only, and loaded anywhere over the projecting portion is called a SEMI-GIRDER or CANTILEVER.

600. **Horizontal Beams.**—The BEAMS in ordinary use in Engineering are usually *horizontal*, and *laid on horizontal supports* It will be convenient (for brevity) to confine attention to these; accordingly the term Beam in this Chapter is to be understood as "Horizontal Beam on horizontal supports".

[*N.B.*—This limitation is solely to avoid circumlocution: the principles in this Chapter are applicable, *mutatis mutandis* to Beams in any position].

601. **Transverse, Direct, Twisting-Strain.**—The whole of the External Forces or Loads applied to a Horizontal Beam may clearly be resolved into three sets:—

1°. VERTICAL.—These alone produce Transverse Strain; the investigation of this TRANSVERSE STRAIN *alone* will be treated in this Chapter.

[*N.B.*—These also produce Twisting Strain, but seldom to any great extent in actual Engineering Structures].

* By the same author.

† Also in the new College Manual of Applied Mechanics.

2°. Horizontal-Longitudinal (*i. e.*, along the Beam).—These produce *direct* Strain and Stress along the Beam, which have been fully considered in Chapter XXV.

3°. Horizontal-Transverse.—These produce Twisting Strain, but seldom to any great extent in actual Engineering Structures.

602. **Mode of support.**—The mode of support of a Beam has an *important* influence on its Strength, *see* Table in Art. 607. The following terms will be employed for brevity to distinguish the usual modes of support:—

1°. Cantilever.—Fixed at one end.

2°. Supported Beam.—Supported freely at both ends.

3°. Fixed Beam.—Supported and fixed (in direction) at both ends.

4°. Supported and Fixed Beam.—Supported at both ends, and fixed (in direction) at one end.

603. **Bending, Flexure, Deflexion.**—The principal *observed* effect of Transverse Load on a Beam is Bending, Flexure, or Deflexion. Some of the laws of flexure will be stated hereafter. It is sufficient to state here that the Deflexion is generally greatest at the point where the Resultant of applied external Loads acts, *i. e.*, opposite the greatest Load.

604. **Nature of Transverse Strain.**—A simple experiment will show that Transverse Strain is of complex character, and resolvable into the simple strains of Tension, Pressure, and Shear, producing, therefore, *simultaneously* Tensile, Crushing, and Shearing Stresses in the material.

605. **Breaking Weight, Working Stress.**—The design of Beams to resist Transverse Strain admits of two distinct methods of treatment.

(i). *From the Breaking Weight, or Load which applied transversely in a given manner will break the Beam across.*

(ii). From consideration of the *simple* Stresses, *i. e*, by resolution of the *effect* of a Load applied transversely into the *simple* Stresses (Longitudinal, *i. e.*, Tensile and Compressive; and Tangential, *i. e.*, Shearing) which it actually produces in the different parts or pieces of the Beam, which are therefore the "Working Stresses" on those parts.

606. *Comparison of Methods*—(i). Method i, of designing from the Breaking Weight which applied transversely would *break* the Beam across, is by far the simpler, and more rapid way, but it is entirely dependent on *experiment* on Beams *of similar kind, similarly loaded*, and is, therefore, not easily susceptible of generalization to Beams *different* and *differently*

loaded to those experimented on. It has also the advantage, when *limited* to the class of Beam and particular loading *experimented on*, of being independent of any hypotheses as to the state of strain. On account of its simplicity, this method is recommended for unimportant cases in which economy of material is not of much importance (*e. g.*, in solid wooden beams or joists).

(ii). Method ii of designing *each portion* of a Beam to bear the Working Stress that actually falls on it is (except for solid sections) the only really scientific method, *i. e.*, the only one by which an economical *arrangement* of material can be made. It is far more difficult than Method i, and *as usually applied* is *strictly* only applicable to those materials for which the moduli of direct (*i e.*, Tensile and Crushing) Elasticity are nearly equal ($E_t = E_c$). This last objection is not inherent in the method, the principles of which are broad enough to embrace any material, but the usual *(almost universal) mode of its application does so limit it. This must be* carefully borne in mind.

[*N. B.*—This method will be fully treated of in the 3rd Edition of Vol. II of this Treatise].

Method (i)

607. The formulæ of this method all give the Breaking Weight (P). With these must of course be combined the fundamental formulæ,

$$P = sW, \text{ or } P = s'W' + s''W'', \ldots\ldots\ldots\ldots (1).$$

of Art. 457, when the *Working Load* (W) *is in question.*

608. It has been ascertained *by experiment*, that in Beams which are *similar, similarly loaded and supported*, the Breaking Weight varies *as* the *breadth* and *square* of the *depth*, and *inversely as* the length, *i. e.*, (for Notation, *see* Art. 461).

$$P \propto \frac{bd^2}{L}, \text{ or } P = (\text{constant}) \times \frac{bd^2}{L} \ldots\ldots\ldots\ldots (2)$$

N.B.—This constant is of course derived from experiment: the Result (1) furnishes at once the Breaking Weight (P) of Beams *similar, similarly loaded and supported to those for which the above "constant" has been* determined by experiment (but of no others).

This "constant" has been commonly *recorded* only for *one* case for which it is called the "Modulus of Rupture", thus

p_b = "Modulus of Rupture", or "Modulus of Transverse Strength".

2°. Horizontal-Longitudinal (*i. e.*, along the Beam).—These produce *direct* Strain and Stress along the Beam, which have been fully considered in Chapter XXV.

3°. Horizontal-Transverse.—These produce Twisting Strain, but seldom to any great extent in actual Engineering Structures.

602. Mode of support.—The mode of support of a Beam has an *important* influence on its Strength, *see* Table in Art. 607. The following terms will be employed for brevity to distinguish the usual modes of support:—

1°. Cantilever.—*Fixed at one end.*

2°. Supported Beam.—Supported freely at both ends.

3°. Fixed Beam.—Supported and fixed (in direction) at both ends.

4°. Supported and Fixed Beam.—Supported at both ends, and fixed (in direction) at one end.

603. Bending, Flexure, Deflexion.—The principal *observed* effect of Transverse Load on a Beam is Bending, Flexure, or Deflexion. Some of the laws of flexure will be stated hereafter. It is sufficient to state here that the Deflexion is generally greatest at the point where the Resultant of applied external Loads acts, *i. e.*, opposite the greatest Load.

604. Nature of Transverse Strain.—A simple experiment will show that Transverse Strain is of complex character, and resolvable into the simple strains of Tension, Pressure, and Shear, producing, therefore, *simultaneously* Tensile, Crushing, and Shearing Stresses in the material.

605. Breaking Weight, Working Stress.—The design of Beams *to resist Transverse Strain admits of two distinct methods of treatment.*

(i). From the Breaking Weight, or Load which applied transversely in a given manner will *break* the Beam *across.*

(ii). From consideration of the *simple* Stresses, *i. e.*, by resolution of the *effect* of a Load applied transversely into the *simple* Stresses (Longitudinal, *i. e.*, Tensile and Compressive; and Tangential, *i. e.*, Shearing) which it actually produces in the different parts or pieces of the Beam, which are therefore the "Working Stresses" on those parts.

606. *Comparison of Methods*—(i). Method i, of designing from the Breaking Weight which applied transversely would *break* the Beam across, is by far the simpler, and more rapid way, but it is entirely dependent on *experiment* on Beams *of similar kind, similarly loaded*, and is, therefore, not easily susceptible of generalization to Beams *different* and *differently*

loaded to those experimented on. It has also the advantage, when *limited* to the class of Beam and particular loading experimented on, of being independent of any hypotheses as to the state of strain. On account of its simplicity, this method is recommended for unimportant cases in which economy of material is not of much importance (*e g.*, in solid wooden beams or *joists*).

(ii). Method ii of designing *each portion* of a Beam to bear the Working Stress that actually falls on it is (except for solid sections) the only really scientific method, *i. e.*, the only one by which an economical *arrangement* of material can be made. It is far more difficult than Method i, and *as usually applied* is *strictly* only applicable to those materials for which the moduli of direct (*i. e.*, Tensile and Crushing) Elasticity are nearly equal ($E_t = E_c$). This last objection is not inherent in the method, the principles of which are broad enough to embrace any material, but the usual (almost universal) mode of its application does so limit it. This must be carefully borne in mind.

[*N. B.*—This method will be fully treated of in the 3rd Edition of Vol. II of this Treatise].

METHOD (i).

607. The formulæ of this method all give the Breaking Weight (P). With these must of course be combined the fundamental formulæ,

$$P = sW, \text{ or } P = s'W' + s''W'', \ldots\ldots\ldots\ldots\ldots\ldots (1).$$

of Art. 457, when the Working Load (W) is in question.

608. It has been ascertained *by experiment*, that in Beams which are *similar, similarly loaded and supported*, the Breaking Weight varies *as* the *breadth* and *square* of the *depth*, and *inversely as* the length, *i. e.*, (for Notation, *see* Art. 461).

$$P \propto \frac{bd^2}{L}, \text{ or } P = (\text{constant}) \times \frac{bd^2}{L} \ldots\ldots\ldots\ldots\ldots (2)$$

N.B.—This constant is of course derived from experiment: the Result (1) furnishes at once the Breaking Weight (P) of Beams *similar, similarly loaded and supported* to those for which the above "constant" has been determined by experiment (but of no others).

This "constant" has been commonly *recorded* only for *one* case for which it is called the "Modulus of Rupture", thus

p_b = "Modulus of Rupture", or "Modulus of Transverse Strength".

2°. Horizontal-Longitudinal (*i. e.*, along the Beam).—These produce *direct* Strain and Stress along the Beam, which have been fully considered in Chapter XXV.

3°. Horizontal-Transverse.—These produce Twisting Strain, but seldom to any great extent in actual Engineering Structures.

602. Mode of support.—The mode of support of a Beam has an *important* influence on its Strength, *see* Table in Art. 607. The following terms will be employed for brevity to distinguish the usual modes of support:—

1°. Cantilever.—Fixed at one end.

2°. Supported Beam.—Supported freely at both ends.

3°. Fixed Beam.—Supported and fixed (in direction) at both ends.

4°. Supported and Fixed Beam.—Supported at both ends, and fixed (in direction) at one end.

603. Bending, Flexure, Deflexion.—The principal *observed* effect of Transverse Load on a Beam is Bending, Flexure, or Deflexion. Some of the laws of flexure will be stated hereafter. It is sufficient to state here that the Deflexion is generally greatest at the point where the Resultant of applied external Loads acts, *i. e.*, opposite the greatest Load.

604. Nature of Transverse Strain.—A simple experiment will show that Transverse Strain is of complex character, and resolvable into the simple strains of Tension, Pressure, and Shear, producing, therefore, *simultaneously* Tensile, Crushing, and Shearing Stresses in the material.

605. Breaking Weight, Working Stress.—The design of Beams to resist Transverse Strain admits of two distinct methods of treatment.

(i). From the Breaking Weight, or Load which applied transversely in a given manner will *break* the Beam *across*.

(ii). From consideration of the *simple* Stresses, *i. e.*, by resolution of the *effect* of a Load applied transversely into the *simple* Stresses (Longitudinal, *i. e.*, Tensile and Compressive; and Tangential, *i. e.*, Shearing) which it actually produces in the different parts or pieces of the Beam, which are therefore the "Working Stresses" on those parts.

606. *Comparison of Methods*—(i). Method i, of designing from the Breaking Weight which applied transversely would *break* the Beam across, is by far the simpler, and more rapid way, but it is entirely dependent on *experiment* on Beams *of similar kind, similarly loaded*, and is, therefore, not easily susceptible of generalization to Beams *different* and *differently*

loaded to those experimented on. It has also the advantage, when *limited* to the class of Beam and particular loading experimented on, of being independent of any hypotheses as to the state of strain. On account of its simplicity, this method is recommended for unimportant cases in which economy of material is not of much importance (*e. g.*, in solid wooden beams or joists).

(ii). Method ii of designing *each portion* of a Beam to bear the Working Stress that actually falls on it is (except for solid sections) the only really scientific method, *i. e.*, the only one by which an economical *arrangement* of material can be made. It is far more difficult than Method i, and *as usually applied* is *strictly* only applicable to those materials for which the moduli of direct (*i. e.*, Tensile and Crushing) Elasticity are nearly equal ($E_t = E_c$). This last objection is not inherent in the method, the principles of which are broad enough to embrace any material, but the usual (almost universal) mode of its application does so limit it. This must be carefully borne in mind.

[*N. B.*—This method will be fully treated of in the 3rd Edition of Vol. II of this Treatise].

METHOD (i).

607. The formulæ of this method all give the Breaking Weight (P). With these must of course be combined the fundamental formulæ,

$$P = sW, \text{ or } P = s'W' + s''W'', \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

of Art. 457, when the Working Load (W) is in question.

608. It has been ascertained *by experiment*, that in Beams which are *similar, similarly loaded and supported*, the Breaking Weight varies *as* the *breadth* and *square* of the *depth*, and *inversely as* the length, *i. e.*, (for Notation, *see* Art. 461).

$$P \propto \frac{bd^2}{L}, \text{ or } P = (constant) \times \frac{bd^2}{L} \ldots\ldots\ldots\ldots\ldots (2)$$

N.B.—This constant is of course derived from experiment: the Result (1) furnishes at once the Breaking Weight (P) of Beams *similar, similarly loaded and supported* to those for which the above "constant" has been determined by experiment (but of no others).

This "constant" has been commonly *recorded* only for *one* case for which it is called the "Modulus of Rupture", thus

p_b = "Modulus of Rupture", or "Modulus of Transverse Strength".

4 F

= Weight (in pounds) which, applied evenly across the middle of a *straight horizontal uniform* Beam *of* 1″ × 1″ *scantling*, simply laid on two supports 1 foot apart (in the clear), will just break it.

Then, for *such* Beams (*i. e.*, of *uniform rectangular* section, *so* loaded and supported).

$$P = p_b \cdot \frac{bd^2}{L} \text{ ....} (3).$$

N.B.—p_b is ascertained *by experiment* as set forth : it is recorded only for Timber ; for its values for Indian Woods, *see* Chapter V., Sec. I. For other Woods and other materials, the values of $f_b = 18\, p_b$* are recorded in Appendix II.

It has also been found *by experiment* that the "Ultimate Transverse Strength", or Breaking Weights of *similar* Beams differing as follows *in their Load* and *mode of Support* are as shown in the following Table. The Table shows the ratios of the Breaking Weights of *similar* Beams (of *any* form), and also the actual value of the Breaking Weight (P) in pounds for Beams of uniform rectangular cross-section.

Case	Beam.	Support.	Load.	Ratio of Breaking Weights in *similar* Beams	Breaking Weights (P) in pounds for uniform rectangular Beams.	Equation.
i	Cantilever or Semigirder.	Fixed at one end,	At free end,	$\frac{1}{4}$	$\frac{1}{4}\, p_b \cdot bd^2 \div L$	(4).
ii			Uniform,	$\frac{1}{2}$	$\frac{1}{2}\, p_b \cdot bd^2 \div L$	(5).
iii	Beam,	Freely supported at both ends,	At middle,	1	$p_b \cdot bd^2 \div L$	(6).
iv			Uniform,	2	$2\, p_b \cdot bd^2 \div L$	(7).
v			At point x', x'' from either end,	$\frac{1}{4} \cdot \frac{L^2}{x'x''}$	$\frac{1}{4}\, p_b \cdot bd^2\, L \div (x'x'')$	(8).
vi	Beam,	Fixed at both ends,	At middle,	$\frac{3}{2}$	$\frac{3}{2}\, p_b \cdot bd^2 \div L$	(9).
vii			Uniform,	3	$3\, p_b \cdot bd^2 \div L$	(10).
viii			At point x', x'' feet from either end,	$\frac{3}{8} \cdot \frac{L^2}{x'x''}$	$\frac{3}{8}\, p_b \cdot bd^2\, L \div (x'x'')$	(11).

* The definition of f_b and explanation of the relation $f_b = 18\, p_b$ will be given in the 2nd Volume of this Treatise (3rd Ed.), and in the College Manual of Applied Mechanics.

609. Fixed Beam.—It would appear from comparing Results (6, 7, 8) with (9, 10, 11) respectively that the Ultimate Strength of a supported Beam was in each case of Loading set forth *increased* by fixing its ends in the ratio 3 : 2. These Results (9, 10, 11) are quoted from Barlow's Strength of Materials, Ed. 1845. Result (9) was obtained by P. Barlow *by actual experiment* on *Ultimate* Strength (Breaking Weight), but the evidence of Results (10), (11) is not stated. Results (9) and (11) differ remarkably from the corresponding Results obtained by Method ii for the Working Strength, that is to say the Working Strength of *Fixed Beams* does not appear to be connected with the Ultimate Strength by any such simple relation as $P = sW$, or

"Ultimate Strength = Constant (factor of safety) × Working Strength"

As the Working (not the Ultimate) Strength is the only important question in Engineering, the real utility of Results (9, 10, 11) seems questionable.

[*N.B.*—An investigation is given in Barlow's Essay on Strength and Stress of Materials (1826), and Treatise on Strength of Timber, &c. (1845), purporting to show that the ratio ought to be 3 : 2 for the Working Strength of Cases iii and vi, but the proof is *defective*. For a full discussion of the evidence of Results (9, 10, 11) *see* Paper LII. of "Professional Papers on Indian Engineering," Second Series, 1872, "On Beams Fixed and Supported" by the present writer]

610. *Application to Timber.*—The Table gives all that is ordinarily required for Simple Wooden Beams of *uniform rectangular cross-section* (the usual form), *i.e.*, it gives for the eight ordinary modes of Load and support.

(1).—The Breaking Weight (P) and Working Load (W) for a given Beam (in which b, d, l are known).

(2).—The value of bd^2 for a Beam to carry a given Load W (= P ÷ s = factor of safety, Art. 457).

The value of either b or d or the ratio $b : d$ is usually fixed from practical considerations, thus

1°. In flat roofs the breadth b of the joints on which the bricks or tiles is generally made 3 inches, thus giving $1\frac{1}{2}$ inches bearing to each brick or tile resting on it.

2°. The ratio $b : d$ may be conveniently taken as $1 : \sqrt{2}$ or as $2 : 3$, d being *generally* taken > b because the ULTIMATE STRENGTH (which is measured by the Breaking Weight or Ultimate Resistance, Art. 456-1) increases as the *square* of the depth, *i.e.* much more rapidly with the depth,

formulæ *together*, because in order that formulæ may be used *together*, *i. e.*, that they may form *simultaneous* equations, the *conditions* under which *both* are applicable must be observed.

In using these formulæ *together* therefore, the Breaking weight (P) and Modulus of Transverse Strength (p_b) must be divided by *such* "a factor of safety" (s), that the resulting Working Load (W) shall bend the *actual* Beam *only very slightly*, *i.e.*, that the ratio $\delta : l$ shall be a very small quantity.

If this precaution be neglected, no confidence whatever can be placed in the result of combining the equations of Art. 608 and 614, as if they were simultaneous equations].

Keay's Method.—A method devised by Ensign P. Keay, was given in the previous (1st and 2nd) Editions of this Treatise, and in the College Manuals on Strength of Materials previous to 1873, whereby it was proposed, *after* assigning the ratio $b : d$ for Timber Beams from other practical considerations of convenience (*e. g.*, as $1 : \sqrt{2}$), to find from the Deflexion-formula such a "factor of safety" (s)—in this case a function of the length L—that the Transverse Strength Formulæ $\left(W = \frac{P}{s} = \frac{p_b}{s} \cdot \frac{bd^2}{L}\right)$ should yield *the same result* as the Deflexion Formulæ. The *utility* of this proceeding is questionable, because the original Deflexion-Formula *alone* would yield the required result, and is itself more simple than the *modified* Transverse Strength Formula proposed for use.

The modification is troublesome, and is therefore omitted from this Edition.

It may be here stated that objections have been raised to Mr. Keay's method on *theoretical* grounds in "Professional Papers on Indian Engineering," Second Series, No. VIII, "On Deflexion of Timber and Factor of Safety" by the late Mr. Valentine. Mr. Valentine's own paper is however so full of theoretical mistakes that *no conclusions* can be drawn from it. It may also be stated that Mr. Keay's method really did effect the object proposed, and that, if the Transverse Strength Formula is used *as above set forth* $W = \frac{p_b}{s} \cdot \frac{bd^2}{L}$ (*i. e.*, the strain confined *within the limits* of Elasticity) and the ratio $\delta : l$ be chosen (as it always is) *a very small quantity*, the condition of Art. 615 (viz., that the Beam be *only slightly* bent) is satisfied, so that the Formulæ of Transverse Strength and Deflexion are under the *same conditions*, and therefore are *simultaneous*, and Mr. Keay's method is unobjectionable.

APPENDIX.

MANUFACTURE OF CEMENT IN INDIA.

In connection with the "Rules for Manufacture of Cement in India," printed on page 120, the following additional notes by Col. H. A. Brownlow, R.E., and P. Dejoux, Esq., will be found interesting and instructive.

Remarks on Col. H. A. Brownlow's Report by P. Dejoux, Esq.

The rates estimated by Col. Brownlow for cement delivered in Delhi are very correct, but it will not do to calculate on more than 4 cubic feet of cement in pretty good order in a cask, as the remainder will be found spoilt during the shipping, or during transit from Calcutta to Delhi.

I have myself received in Calcutta nearly 10,000 casks of cement, and from experience I always found an average of 4 cubic feet of cement in good order per cask.

Accordingly the rate of Portland cement at Delhi should be 5·66, instead of 5·2.

I do not quite agree with Col. Brownlow as regards the advantage in India of using clay and pure slaked lime instead of clay and *chalk*. Without considering the increase in the cost on account of the double burning, I think the burning is always more difficult in one case than in the other, and the tenacity of the cement is never so good.

If a prejudicial action takes place on account of the Oxyde of Iron, I would advise the use of clay either entirely free from, or containing a small portion of it.

(5). *Cement of Boulogne.*—The best marly clay used in France is that found in Boulogne, with which Messrs. Demarle and Co., manufacture a cement in high demand in France.

I have been using it in large quantities for three years in the manufacture of artificial stone (Coignet's system), and found it even sensibly better than the Portland cement of Messrs. White Brothers, which is considered as one of the best sort in England.

The Boulogne marly clay contains from 19 to 25 per 100 of clay.

Every sort of clay containing more than ½th per 100 of sand is to be rejected.

To be certain of a good homogeneity the clay is pulverized and mixed with water in vats, the water is then removed by decantation, and the clay being thus by evaporation in a sufficiently stiff state to be moulded, balls are made of it and burnt in a kiln up to a white heat.

The white heat is necessary for the spreading of the bad parts, which are picked, and rejected carefully after the burning.

The cement is afterwards ground in fine powder, and sifted through a sieve of 60 meshes to 1 inch.

(6). *Cement in the neighbourhood of Paris.*—Sometimes clays may be found homogeneous enough to enable their being burnt without the process of either pulverization or washing. The clay found near Paris contains about the same proportion of Silica and Alumina as that of Boulogne. Such descriptions of marly clay are found (in beds) close to the beds of Gypsum (or Sulphate of Lime); great care must however be observed in selecting them to avoid the mixture of Gypsum with them. These may be burnt in their natural state, and treated after the same manner as the cement of Boulogne.

The best factories are those of Messrs. Barbier and Co. at Paris, Chronne, and Argenteuil, Messrs. Slacker and Letellier at the Butts Chaumont, the Moulineaux and the Rainey.

I used these cements, particularly the first sort, for the building of several miles of sewer in Paris, and found it not much inferior to the English Portland.

(7). *Marly clays.*—I feel almost sure that marly clays of about the same composition as those of Boulogne or Paris may be found in the proximity of many lime quarries now existing in India, and I opine therefore that a careful search will enable the discovery of materials well adapt-

Papers by P. Dejoux, Esq., on Manufacture of Lime, Mortar and Concrete in Bengal.

MANUFACTURE OF GHOOTING LIME.*—Lime as a rule ought to be sifted fine enough to be free of all unburnt or overburnt particles which do not slake immediately, but which may slake after a certain time, and consequently may injure the quality of the mortar.

As ghooting lime, from want of homogeneity, can never be well burnt, a fine sifting of the lime after slaking will largely increase the cost of the lime.

In grinding the lime and the unburnt portion, which ought to pass through a sieve of 8 meshes to one inch, some of the parts not slaked may act as cement, while others will remain inert.

It may happen that in the case of the presence of *Chaux limites*† (Argillaceous intermediate limes), some other parts slaked a long time after, and falling in powder may disintegrate some portions of the mortar.

It is, however, very difficult to ascertain the presence of the *chaux limites*, but as far as I can judge, I do not think there is much probability of finding them amongst the generality of ghooting.

My opinion however, is, that the best and cheapest way to deal with the manufacture of ghooting limestone consists in the following plan:—

1st.—To burn the ghooting limestone in a kiln, as per *Plate* XVIIIa. Before burning, the kiln must be, if necessary, carefully plastered, both outside and inside, with a mortar composed of four parts of clay and one of lime. First a layer of 6 inches of coal is to be put, then 9 inches of ghooting, then 3 inches of coal, and then 9 inches of ghooting, &c., &c.; the last layer must be of ghooting proceeding from the last burning, and which not being perfectly burnt is generally called "refuse ghooting."

With some limestones 2 inches of coal will suffice. I have noticed that, owing to kilns being built generally in a careless manner, the loss of caloric must be enormous in them. The firing of the kilns may be begun when three layers of stone have been put in it. A portion of the openings may be shut, leaving sufficient room for ventilation according to

* Bengalli for "kunkur lime," containing 26 to 34 per cent. of clay.

† An explanation of this term will be found in Vicat on Limes and Cements *Chaux limites* are limes obtained from stones containing too large a proportion of clay to be hydraulic limestones, and too small a proportion to be cement stones.

the state of the weather. It will be advisable, as a preventive against the effect of the stormy winds, when the fire is likely to arrive to the uppermost layer, to have screens of corrugated iron put on the top of the kiln in the direction of the prevailing wind. Lime is frequently very badly burnt, solely from want of this precaution. When the unloading of the kiln is commenced, the iron bars are to be taken out, and then ⅓rd of the total height of the stone inside may be discharged, and the kiln reloaded. It will be advisable, when the kiln is in full blaze, to refit the bars every eight days, and by such means to remove the ash from the ash holes, and enliven the fire.

2nd.—As soon as the lime is burnt, it is to be taken out of the kiln *immediately*, and the stone separated from the ashes. The limestone is then set against a wall in layers of about 4 inches. On each layer water is to be thrown by means of garden watering pots. A heap of about 5 or 6 feet high may be made, and the ghooting may be left in this state for about four days; the top of the heap should be watered a little on the second day. After the expiration of four days, it must be sifted through a sieve of 8 meshes to one inch.

It will be judicious always to put the burnt stone in large and high heaps, because by this being done, the heat will be concentrated, and the slaking facilitated. As regards the sifting, I think for large works it will be better to use a revolving sifting machine as used in France.

3rd. The lime will then be pulverized in a soorkee mill separately, or mixed with the sand necessary for the mortar.

Sand mortar.—I would advise the use always of sand, instead of soorkee, when sharp clean sand of middling size is obtainable. Soorkee ought to be used only when sand cannot be obtained, and for this reason:

If the lime is very hydraulic, the soorkee which is very often made from bricks imperfectly burnt, *acts only as an inert body;* in such a case sand, which is harder, has evidently the advantage over soorkee; sand has also the great advantage that it is generally much cheaper.

* The advisability of this depends entirely upon nature of lime. "Experiments show that a mortar composed of one volume of fat lime, and two volumes trass is injured if a portion of the trass be replaced by sand." Gillmore, para. 560.

* May even act prejudicially, *vide* note on next page.

* Notes by Col. H. A. Brownlow, R.E.

If the lime is not hydraulic enough, and if no other kind of puzzuolana can be obtained, soorkee made with first rate burnt bricks, and reduced to impalpable powder, will increase the hydraulicity of the lime,* but as it has been said before, the soorkee generally used is prepared with bricks imperfectly burnt, on account of such bricks being more brittle, and the powder is always too coarse to act efficiently as a puzzuolana.

Mortar made with soorkee seems after a short time harder than sand mortar, but after a long time sand mortar, if well made, will be found superior. One of the greatest precautions to be taken with sand mortar is to have the bricks or stones thoroughly soaked in water; the default of using this precaution is the great cause of the apparent inferiority of the sand mortar as compared with the soorkee mortar, because the soorkee retains much more moisture than the sand.

Comparatively *less* water ought to be used in the manufacture of sand mortar, than that of soorkee mortar, as it (the mortar) must be made to the consistency of a plastic paste.

Care must be taken in the sand mortar, especially to prevent too rapid drying, because hydraulic lime being an anhydrous silicate of lime, (with an excess of lime,) which gets hard by the *hydration* of the lime, it is evident, therefore, that a certain degree of moisture is necessary. But water must, however, not be thrown on the mortar before it has commenced to set sensibly, for the water might wash away the lime.

During the time necessary for the setting, the masonry ought to be covered either with wet mats, wet straw, or wet sand.

* The greatest care is required in mixing soorkee at all with hydraulic lime. It is only the excess of pure lime that combines advantageously with the soorkee, forming with it silicates and aluminates of lime. But the danger of thereby breaking the set is manifest, for while the natural combinations of lime with the silica and alumina in the hydraulic limes immediately commence to set, those formed between the free caustic lime and the soorkee, will have to effect a preliminary decomposition of the silica and alumina combined in the soorkee and the two dissimilar actions, one composing and the other decomposing, cannot go on in such close connection with any advantage to the mortar. Breaking the set is notoriously most fatal to hydraulic energy, so that kunkur lime should never be left in a mill to be reground after an interval of time. But where pure rich lime is mixed with soorkee, long and intimate mixture is advantageous, because the silica and alumina must free themselves from the combination existing in the soorkee before setting can commence. It is also evident that the finer the soorkee is powdered the better.

* Note by Col. H. A. Brownlow, R.E.

In the case of ghooting lime, it is only after the fourth day the mortar has been used, that watering can be commenced.

In the case of fat lime, the hardness of the lime is caused by the crystallization of the calcareous carbonate recomposed; if the setting is allowed to take place too soon, an incomplete crystallization will be attained, together with some carbonate in a pulverulent state.

In a hot climate like that in India, in the case of hydraulic mortars, which take a long time to arrive at the maximum of hardness, it is absolutely necessary to proceed with the watering until the mortar is pretty hard both outside and inside.

Puzzuolana.—There is a kind of puzzuolana which is, I think very commonly found in India, in places when laterite exists; it is made of red ochre earth. The ochre I received from Orissa has yielded a good result, and I have since found ochre of about the same description at Midnapore, which promises the same results.

By using this puzzuolana with mortar in the following proportions:—

3 Sand,		1 Sand.
2 Lime,	or	1 Lime.
1 Puzzuolana,		1 Puzzuolana.

the quickness of setting of the mortar will be augmented to a great extent; the cost of such a puzzuolana on the spot, as far as I can judge now, will be from 4 to 6 annas per cubic foot.

Concrete.—In the concrete I would advise also the use of sand, instead of soorkee.

To ascertain the quantity of mortar necessary for the making of a good concrete, it is necessary to take a water-tight box measuring one cubic foot, and fill it first with khoa, broken stone, or pebble (which are to be used in the concrete), and then with water. The quantity of water is then to be measured, and this will be found equal to the quantity of mortar necessary to fill interstices.

* The volume of mortar should, however, always be somewhat in excess of this, to allow for imperfect mixture.

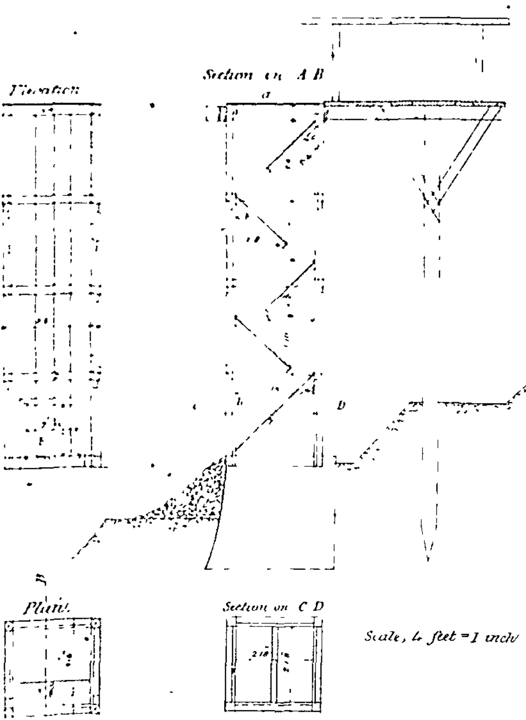
As regards broken bricks or stone in small pieces, the quantity of mortar required for 100 cubic feet of broken bricks, varies from 46 to 50 cubic feet of mortar.

In the case of pebbles and small round stones, 100 cubic feet of stones will require from 37 to 40 cubic feet of mortar.

* Note by Col. H. A. Brownlow, R.E.

MANUFACTURE OF CEMENT IN INDIA.

BETONNIERE.



For mixing khoa or stones with mortar, I strongly advise the use of a "Betonniere" of the kind I have seen used in France, of which I annex a drawing (*Plate* XVIII*b*.) I gave last year to the Executive Engineer, Cossye Division, a sketch of such a "Betonniere." Some were made accordingly by him, and have been used with great success in his works.

The mode of using such an apparatus consists only in throwing the materials inside by the opening (*a*), and in taking care to throw alternately two baskets of khoa and one of mortar, if the proportions of the concrete are 2 to 1, and thus the whole comes out from the machine by the opening (*b*) perfectly mixed.

With a "Betonniere" 1,000 cubic feet of concrete can be manufactured easily per day.

The cost of one will be about Rs. 150.

GENERAL REMARKS ON GHOOTING LIMESTONES.

The nodular limestone, called *Ghooting* or *kunkur* in India, generally is by its chemical properties the combination of a hydraulic stone and a cement stone, rather a little too rich in clay, so that when the stones are not too hard to break, pulverizing and mixing them with sufficient water to form a rather hard paste, and then making small bricks or balls and burning them sufficiently, will enable the manufacture in some cases of Portland or slow-setting cement, and in other cases a kind of Roman cement or quick-setting cement. When the ghooting is burnt, as is generally done in Bengal, the part which is slaked when taken out from the kiln is the part containing the quantity of clay necessary to make good hydraulic lime; large portions of the parts which are not slaked are those containing more clay and are cement stones; but as generally they contain too large proportions of clay, it will not do to burn those portions again, but, on the contrary, it will be better to burn the whole until they cannot be slaked.

The following details will serve to explain my reasons for adopting this opinion.

I.—When I have to conduct the analysis of a stone of the same kind *as a ghooting-stone*, I select from a cubic foot of stone a dozen pieces of different shapes, sizes, and appearances; I pulverize them roughly, and mix as much as possible the powder so obtained.

I take afterwards a small quantity of it, and reduce it by means of an agate mortar into an impalpable powder, of which, when dried, I take a quantity weighing 150 grains, and it is on this last quantity that the analysis is conducted.

II.—Proceeding in this way, I found that in the Bengal ghooting-stone the proportion of clay various from 10·50 to 33·33 per cent., the average, however, being 25 per cent.

Now, if we look to the analysis of the lime believed to be the most hydraulic of all the limes known, viz., the lime of Theil, (France,) we find that the limestone from which that lime is obtained contains only 14·90 per cent. of clay, and we may further say that few hydraulic limestones at home contain more than 15 per cent., and none more than 20 per cent. of clay.

III.—The analysis of the ghooting stones giving an average proportion of 25 per cent., they could naturally be taken for cement stones, but experience proves them to be only argillaceous limestones.

Therefore we can only say that, if the ghooting-stones were more homogeneous, they could have been classified in the category of natural cement *stones.*

To prove this opinion, I may say that, if we separate some nodules from a piece of ghooting taken in its natural state, it will be found that they generally differ in texture and appearance, and that analysis shows that while some contain as much as 50 and 55 per cent. of clay, others are very nearly pure carbonate of lime.

From the experiments I have made, I feel authorized to say that as regards the generality of ghooting-stones, those which contain from 20 to 25 per cent. of clay are very hydraulic limestones, while those containing only from 10 to 14 per cent. are feebly hydraulic.

As regards those in which the proportions of clay exceed 25 per cent., they produce only a small quantity of lime, and the percentage of portions which cannot be slaked increases proportionately with the quantity of clay.

I have been able to verify the truth of these last remarks in many places in Lower Bengal, where large quantities of ghooting lime are manufactured.

I may, however, state that some ghooting-stones or kunkur may be found sufficiently homogeneous to follow the ordinary rules of hydraulic limestones, but such may very seldom be the case.

IV.—When such a stone as ghooting has been well burnt, all the proportions containing less than 20 per cent. of clay slake when immersed in water, but the portions containing an excess of clay, called generally "refuse ghooting" in Bengal, remain inert.

V.—Now, supposing that, after having burnt ghooting-stone containing an average of 20 per cent. clay, the half only of the total quantity (which we will suppose to be 100 cubic feet) slakes and yields an ordinary hydraulic lime; it must be taken as a datum that this lime proceeded from a limestone containing about 10 per cent. of clay.

Consequently the 50 cubic feet of refuse ghooting, which did not slake, must be considered as an argillaceous limestone, containing about 30 per cent. of clay; bearing in mind that the proportion of clay in the total quantity of 100 cubic feet of ghooting was 20 per cent.

Therefore I draw the conclusion that this ghooting must be considered as the agglomeration of two different stones, *i. e.*, while one yields 10 per cent. of clay, and produces an ordinary hydraulic lime, the other contains 30 per cent., and may be transformable into cement.

VI.—*Again, supposing that the 100 cubic feet of ghooting* contains 30 per cent. of clay, and that we obtain (after slaking) a lime very hydraulic, and 50 cubic feet of refuse ghooting, this lime, according to its degree of hydraulicity, must be considered as proceeding from a limestone yielding about 15 per cent. of clay.

It follows that the refuse ghooting must be considered as an argillaceous stone, yielding about 45 per cent. of clay, and consequently quite useless for the manufacture of either lime or cement.

VII.—Under such circumstances, therefore, we have to consider the two following alternatives, if it be intended to use ghooting for making cements.

In the first case, if the proportion of clay in the refuse ghooting be the proportion generally found in cement stones, we have only to begin by burning the ghooting in the usual way, then to let it slake, separate from the refuse ghooting the lime obtained, and to re-burn the refuse more or less according to requirement for either slow or quick-setting cement.

In the second case, which is the most general, and where the proportion of clay exceeds the limit of the quantity usually found in cement stones, we may follow the theories of Messrs. Minard and Lacordaire (Ingenieurs des Ponts et Chaussées), who are of opinion that some argil-

laceous limestones, of which portions contain clay in excess, may by a long process of calcination with a moderate fire be transformed into cement.

VIII.—The soundness of this fact was nevertheless tested by the experiment I made on the specimen of ghooting-stone A7 from Dinapore, as described in Statement B.

This ghooting yielded a quick-setting cement when calcined with a moderate fire until it would not slake.

We could in such a case as the last use a flame-kiln for calcinating the ghooting to the required degree.

IX.—I must, however, reiterate that it will be more certain and more easy, principally on account of the burning, to choose, for the manufacture of cement, ghooting-stones which, containing the proper proportion of clay, can be easily pulverized, and that in such a case they may be treated similarly as *non-homogeneous marly clay.*

In treating about ghooting limestone, I may as well state that the great defect in hydraulic lime extracted from it and used throughout in Bengal, lies from its not being sifted fine enough. Failures in buildings, are, I believe, ascribable in a great measure to the mortar prepared with this defective lime; for straining ghooting lime properly, however, I am of opinion that no sieves less fine than one of 20 meshes to an inch should be used.

In order, therefore, to give my conjecture a trial and my opinion stability as to the defect above noticed, I made a rough analysis of the ghooting lime used in the Drainage Department of the Calcutta Municipality, and found, as anticipated, the following result:—

Lime, ...	47·0
Clay, ...	6·0
Sand, ...	17·5
Ashes, ...	4·0
Carbonate of line, half burnt, ...	25·5
	100·0

Margohi Cement.

The Margohi quarries are only 10 miles distant from the head works at Dehree, and about 5 from the tramway at Dhodand, which communicates with the head works.

The quarries are at the foot of the hills, and can be worked very easily.

It is evident at present that the Soane Circle contains such of the best materials as will enable the manufacture of good cement. Of the specimens received, two have been found very suitable for the purpose. These are called in French *Marnes Argileuses* (marly clay); one of these, B6, is very nearly like the *Marne of Boulogne Sur Mer*, which produces a cement which is considered by many Engineers better than the English Portland cement; the other marked B7, sent to me as white clay, is also a *Marne*, and by its combination with B6 will enable the manufacture of a cement of the kind which is commonly called *Roman cement.*

The clays B6 and B7 are very friable, and consequently very easily pulverized; on this account it is certain (by reducing them to that state and eventually forming bricks with them) to secure a good homogeneity.

In Statement B. are given the results of the experiments on cement, a rough analysis of these two descriptions of marly clay.

The samples A1, A2, and A3 may be also considered as cement stones, but the layers of these stones are of different qualities; some are cement stones, and others similar to those called by Vicat *Chaux Limites*, which are always dangerous to use.

Should these stones be, however, burnt to a high temperature and attempts made to slake them with boiling water, the result will be that while the portion containing the *Chaux Limites* gets slaked, the other remains unaffected. I opine, therefore, that they must be rejected on account of their want of homogeneity, and principally on account of the presence of the *Chaux Limites;* nevertheless, I intend making further experiments with them.

The clay from Dehree, B9, contains 8 per cent. of sand, but after washing it may be used with marly clay, and besides it may answer, if necessary, to increase for slow-setting cements the proportion of clay.

On the surface of the ground about the Margohi quarries there is to be found a sandy clay to a depth of 12 to 15 feet, after which a kind of shelly, useless, clay.

This shelly clay is found in great abundance with the yellow clay B77, the latter containing 88 per cent. of clay or sand, and 12 per cent. of carbonate of lime, and under it the yellow marly clay B6, which is also plentiful, but which can very easily be distinguished from the shelly clay.

Carriage from Bucknour to Dehree,	..	7 to 8 rupees per 100 maunds.
Ditto ditto Patna,	..	18 rupees ditto ditto.
Coolie labor, per coolie, ...	..	from 1 anna 6 pie to 2 annas.
Fire-wood (rather scarce) per 100 maunds,		7 rupees.
Coal per maund, ...	..	8 annas 6 pie.

I think a patient and deliberate exploration of the range of hills from Margohi to Rohtas, will lead to the discovery of several varieties of useful stones. I intend to carry out a careful research personally, if the Government *sanctions the construction of a small cement factory at Dehree.*

Dehree Division.—My inspection of the quarries of Margohi and Bucknour, and the series of experiments I have already made on the specimens from those quarries, confirm me in the opinion that this is, for the present, the best place for manufacturing both slow and quick-setting cements.

Cement Experiments.—On the 19th of June, upon receipt from the Dehree Division of 160 cubic feet of the following materials, viz., yellow marly clay B6, white marly clay B7, white stone A3, and yellow clay B77, I commenced immediately the manufacture of cements, but instead of hiring monthly or buying a soorkee mill, and an engine for pulverizing the materials, I found it more convenient, and comparatively less expensive to hire one of Messrs. Burn and Company's soorkee mills at Bow Bazaar, at Rs. 18* per day whenever I require it. The materials were sent, and they were very easily reduced in soorkee mills into fine powder, and afterwards I had the following mixtures of raw materials made:—

1st	..	2 parts of B6 1 part of B7	In which the average of clay was 22 per cent.
2nd	..	3 parts of B6 1 part of B7	Average of clay 23 per cent.
3rd	..	2 parts of B6 1 part of B7 ½ part of B77	Average of clay 32¾ per cent.

These I put into vats of the reservoir, which I filled with water, and agitated the whole until the appearance of a perfect homogeneity. The water was afterwards allowed to flow off gently, and the deposit is now drying, and I hope, weather permitting, to see it arrive in a few days to a consistence sufficient to enable me to form cakes, &c.

From all the experiments on a small scale I have hitherto made on the ghooting stones or kunkur, I feel convinced that it will be possible to make good cement with some of them.

* Including cost of coal, tindal, &c.

Nos.	Materials from whence obtained.	Composition.		Remarks.
A48	Gray lime-stone from Rohtas Hill, 24 miles from Dehree,	Carbonate of Lime ...	72 34	Cement stone.
		Clay and Sand ...	27 66	
		(Feeble traces of Oxide of Iron and Carbonate of Magnesia).		
		Total ...	100 00	
B77	Yellow clay found at Margohi, ...	Carbonate of Lime ...	11 30	Good for manufacture of slow-setting cement.
		" of Magnesia	0 70	
		Oxide of Iron	None.	
		Clay { Silica ... Alumina ... }	82·00	
		Sand	6 00	
		Total ...	100 00	
A7	Ghooting-stone from Dinapore, ...	Carbonate of Lime ... } " of Magnesia }	77·00	
		Oxide of Iron	1·00	
		Clay { Silica ... Alumina ... }	32·00	
		Sand	Not appreciable.	
			100 00	

Remarks about the preparation of the samples for cement.

1st.—The samples marked Nos. 1, 2, 3, 4, 5, 6, have been pulverized and passed through a sieve of 60 meshes to one inch. The proportions of each have been carefully measured in volume, after being mixed in water; the water was then removed by decantation, and the mixture left until formed into the consistence of a rather hard paste. Of this paste, balls were made of about 2½ inches in diameter; these balls were exposed to the sun for seven days and burnt in the small kiln with *coke* When taken out from the kiln, they were pulverized and strained through a sieve of 60 meshes to one inch.

The powder thus obtained was mixed with a little water and made into a rather stiff paste of which while a portion was put into a tumbler and immersed in water, of the other a cake was made and left exposed to the air.

The cement in water eventually was tested with the Aiguille of Vicat.

2nd—The samples marked Nos. 9, 11, and 12 were not pulverized, but I put only the stones (well washed previously) in the kiln, and after burning sifted them through the same sieve of 60 meshes.

STATEMENT B.—RESULT OF EXPERIMENTS ON CEMENTS.

Nos.	Composition. Quantities.	Composition. From whence materials were obtained.	Hours taken in burning	In what sort of fire.	Color of stone burnt	When mixed and put in water.	Time taken for the setting in water.	Quality of the cement under water.	Quality of the cake when exposed to the air.	Result up to 1st April, 1872.	Result up to 30th June, 1872.
1	1 part of marly clay, B6, 1 ditto, B7,	Margohi	58	Slow fire	Reddish gray.	March 20th	4 days.	Rather soft.	Pretty hard.	Requires evidently more burning (it retains after burning carbonic acid).	It has been getting harder sensibly in cake and in water.
1'	Ditto	Ditto	19	Ditto	Gray.	March 26th.	H. M. 1 15	Very hard.	Very hard.	The hardness has been increasing very sensibly to the present date (it retains carbonic acid)	Ditto, ditto, but less than 1.
1''	Ditto	Ditto	100	Ditto	White reddish.	March 28th.	40 Ms.	Pretty Hard.	Hard	This will become perhaps after a certain time as good as No 1' (it retains carbonic acid).	As hard as 1' in water, but rather soft in cake.
2	2 parts of marly clay, B6 1 part of ditto, B7,	Ditto	53	Ditto	Gray.	March 18th.	5 hours.	Hard.	Very hard.	Hardness always increasing (it retains carbonic acid).	It has been getting harder sensibly, and it is even better than 1.
2'	Ditto	Ditto	90	Ditto	Reddish gray.	March 23rd.	H. M. 4 30	Ditto	Hard.	Will become as hard as No 2, if not more (retains carbonic acid).	It is about or like 1.
2''	Ditto	Ditto	100	Ditto	Gray, greenish.	March 26th.	4 hours.	Pretty hard.	Pretty hard.	I tried two of the balls burnt at the same time, and found the cement of one after 5 days of immersion in water with slight cracks (it retains carbonic acid).	Less hard in cake than in water as the preceding 2'.

Nos.	Composition.		Hours taken in burning.	In what sort of fire.	Color of stone burnt.	When mixed and put in water.	Time taken for the setting in water.	Quality of the cement under water.	Quality of the cake when exposed to the air.	Result up to 1st April, 1872.	Result up to 30th June, 1872.
	Quantities.	From whence materials were obtained.									
12	1 pt. of ghooting stone, A7.	Dinapore	100	Slow fire.	Greenish gray.	March 26th.	35 Ms.	Very hard	Pretty hard.	The cake has been getting harder very slowly, nevertheless its hardness kept on increasing sensibly.	
1iii	1 part of marly clay, B6, 1 ditto B7, ..	Margohi.	50	Strong fire.	White.	April 1st.	15 m.	Very bad.	Very bad.		*In water and in cake.* It crumbled to powder after four days.
1iv	*Ditto*	*Ditto*	48	Very slow fire	Reddish white.	April 30th.	H. M. 1 20	Hard	Pretty hard.		Retained too much carbonic acid.
2iii	2 parts of marly clay, B6, 1 ditto B7, ..	Ditto	50	Strong fire.	Grayish white.	April 1st.	10 m.	Very bad.	Very bad.		In water and in cake. It crumbled to powder after two days. Contained no carbonic acid.
2iv	Ditto	Ditto	48	Very slow fire	Reddish	April 23rd.	H. M. 1 15	Very hard.	Ditto		Was getting sensibly harder in cake, but crumbled to powder five days after being made. Contained no carbonic acid.
2ivB	Ditto	Ditto	48	Ditto	Ditto	June 20 th	1 30	Hard.	Hard.		Its hardness increased sensibly.
2v	Ditto	Ditto	70	Ditto	White.	May 5th	30 m.	Ditto	Very hard.		Retained little carbonic acid.

slv	1 part B6	Ditto	50	Strong fire.	Gray.	April 1st	Not set	Very bad.	Soft.		After four days crumbled to powder under water.
16	2 parts of marly clay, B6 1 part of limestone, A3	Ditto	50	Very strong fire.	Reddish brown.	April 1st	1 m.	Very bad.	Very bad.		After three days crumbled to powder in water and cake. Retained no carbonic acid.
[illegible]	Ditto	Ditto	46	Very slow fire.	Reddish	April 23rd	45 m.	Hard.	Very soft.		Required more burning. Was found very hard for nearly three weeks, but after that time the cake cracked in different places and began to turn soft.
[illegible]	Ditto	Ditto	60	Ditto	Ditto	April 26th	50 m.	Pretty hard.	Pretty hard.		Required a little more burning. Contained much carbonic acid.
[illegible]	[illegible] parts of [illegible] 1 part of marly clay, B7	Ditto	50	Very strong fire.	Grayish white.	April 1st	5 m.	Very bad.	Very bad.		Crumbled to powder in water and cake after five days. Contained no carbonic acid.
[illegible]	Ditto	Ditto	50	Ditto	Ditto	May 1st	40 m.	Very hard.	Very hard.		Was left exposed to the air for one month, and the absorption thus of carbonic acid was the cause of its turning good.
171	Ditto	Ditto	60	Very slow fire.	Reddish.	April 26th.	25 m.	Very hard.	Hard.		Retained carbonic acid but required more burning.
17ii	Ditto	Ditto	110	Ditto	Reddish grey.	June 10th	35 m.	Ditto	Very hard.		Has had just the burning it required; contains a feeble proportion of carbonic acid. The hardness in this sample increased much more rapidly than in others.
17iii	Ditto	Ditto	48	Very strong fire.	Yellowish gray.	June 15th	10 m.	Very bad.	Very bad.		Crumbled to powder in water and in cake two days after.

No.	Composition. Quantities.	Composition. From whence materials were obtained.	Hours taken in burning.	In what sort of fire.	Color of stone burnt	When mixed and put in water.	Time taken for the setting in water.	Quality of the cement under water.	Quality of the cake when exposed to the air.	Result up to 1st April, 1872.	Result up to 20th June, 1872.
19	4 parts of marly clay, B6 1 part of marly clay, B7	Margohi	50	Very strong fire.	Gray.	April 1st	Not set.	Very bad.	Pretty hard.		Crumbled to powder in water after 24 hours.
19½	Ditto	Ditto	70	Very slow fire.	Red.	April 30th	50 m.	Hard.	Rather soft.		Required evidently more burning.
20	8 parts of marly, clay, B7 1 part do., B16	Ditto	50	Very strong fire.	Gray.	May 5th	4 days.	Very hard.	Pretty hard.		Could stand more burning with a strong fire.
21	1 part stone, 48A	Rohtas	110	Very slow fire.	Grayish white.	June 10th	2 hours.	Hard.	Hard.		Required more burning, and could stand a stronger fire. This will make a good slow setting cement (I had not enough materials to make another experiment).
30	3 parts of marly clay, B6, 1 part of marly clay, B7, 1½ parts of marly clay, B77,	Margohi	70	Very strong fire.	Yellow.	June 20th	H. 3 M. 15	Pretty hard.	Pretty hard.		Its hardness increases very slowly; it required more burning.
30½	Ditto	Ditto	110	Ditto	Grayish yellow.	June 22nd	10 hours	Hard.	Very hard.		It was burnt very near vitrification, but I should think it required a little more burning

Note.—It will be observed from this statement that the best sample is No. 2.

It consists of a mixture of $\left\{ \begin{array}{l} \text{2 parts of marly clay, B6} \\ \text{1 part of ditto, B7} \end{array} \right\}$ from Margohi, which was burnt with a slow fire.

APPENDIX II.

The following Tables referred to in Section V. on Strength of Materials, are extracted (with adaptations*) from

Hodgkinson's Experimental Researches on Strength of Cast-Iron, 1846,
Rankine's Manual of Civil Engineering, 1870, and Useful Rules and Tables, 1870,
Stoney's Theory of Strains, 1866,
Molesworth's Pocket Book of Engineering Formulæ,
Keay's Scantlings of Timbers for Roofs, 1872,

and carefully verified with them. All the quantities are from the nature of the case only approximate: this is especially the case with the Constants of Strength.

Explanation of Tables.

Tables I. and II. of 3·6th and 1·7th powers are intended for use with Hodgkinson's Formulæ for "Very Long Pillars", Eq. 10, 11, 12, Art. 516, Chapter XXIII.

Table III. contains the specific gravities and weights per cubic foot of many Materials useful to the Engineer, not inserted in Tables IV. to VII. because their constants of strength are not known.

Tables IV. to VII. contain the specific gravities, and weights in pounds to a cubic foot (w), also (for Metals) in pounds to a cubic inch, and the *linear* expansion (of Metals) between 32° and 212° F: (their *rate* of linear expansion per degree Fahr. is of course $\frac{1}{180}$ of that tabulated), and the Moduli of Tensile, Crushing, and Transverse Strength (f_t, f_c, f_b), and of Tensile Elasticity (E_t) in pounds per square inch, also (for Metals) of Tensile Strength in tons per square inch, *i.e.*, $f_t \div 2240$.

For the definition of these quantities, *see* as follows —

f_t in Art. 481, Chap. XXII. f_c in Art. 504, Chap. XXIII.
f_b in Art. 461, Chap. XXI. E_t in Art. 543, Chap. XXIV.

The values of w, $E_d = \frac{1}{432} \cdot E_t$, f_t, $p_b = \frac{1}{18} f_b$, for all the common Indian woods are tabulated at end of Chap. V. Sec. I., *q. v.*

[illegible] Woods (Sál and Teak), wh[illegible] V).

[illegible]

* By the writer of Section V.

No.	Composition. Quantities.	Composition. From whence materials were obtained.	Hours taken in burning.	In what sort of fire.	Color of stone burnt	When mixed and put in water.	Time taken for the setting in water.	Quality of the cement under water.	Quality of the cake when exposed to the air.	Result up to 1st April, 1872.	Result up to 30th June, 1872.
18	4 parts of marly clay, B6 1 part of marly clay, B7	Margohi	50	Very strong fire.	Gray.	April 1st	Not set.	Very bad.	Pretty hard.		Crumbled to powder in water after 24 hours.
18i	Ditto	Ditto	70	Very slow fire.	Red.	April 30th	50 m.	Hard.	Rather soft.		Required evidently more burning.
20	8 parts of marly, clay, B7 1 part do., B16	Ditto	50	Very strong fire.	Gray.	May 5th	4 days.	Very hard.	Pretty hard.		Could stand more burning with a strong fire.
24	1 part stone, 48A	Rohtas	110	Very slow fire.	Grayish white.	June 10th	2 hours.	Hard.	Hard.		Required more burning, and could stand a stronger fire This will make a good slow setting cement (I had not enough materials to make another experiment).
30	3 parts of marly clay, B6, 1 part of marly clay, B7, 1¼ parts of marly clay, B77,	Margohi	70	Very strong fire.	Yellow.	June 20th	H. 3 M. 15	Pretty hard.	Pretty hard.		Its hardness increases very slowly; it required more burning.
20i	Ditto	Ditto	110	Ditto	Grayish yellow.	June 22nd	10 hours	Hard.	Very hard.		It was burnt very near vitrification, but I should think it required a little more burning.

Note.—It will be observed from this statement that the best sample is No. 2.

It consists of a mixture of { 2 parts of marly clay, B6 / 1 part of ditto, B7 } from Margohi, which was burnt with a slow fire.

APPENDIX II.

The following Tables referred to in Section V. on Strength of Materials, are extracted (with adaptations*) from

Hodgkinson's Experimental Researches on Strength of Cast-Iron, 1846,
Rankine's Manual of Civil Engineering, 1870, and Useful Rules and Tables, 1870,
Stoney's Theory of Strains, 1866,
Molesworth's Pocket Book of Engineering Formulæ,
Keay's Scantlings of Timbers for Roofs, 1872,

and carefully verified with them. All the quantities are from the nature of the case only approximate: this is especially the case with the Constants of Strength.

Explanation of Tables.

Tables I. and II. of 3·6th and 1·7th powers are intended for use with Hodgkinson's Formulæ for "Very Long Pillars", Eq. 10, 11, 12, Art. 516, Chapter XXIII.

Table III. contains the specific gravities and weights per cubic foot of many Materials useful to the Engineer, not inserted in Tables IV. to VII. because their constants of strength are not known.

Tables IV. to VII. contain the specific gravities, and weights in pounds to a cubic foot (W), also (for Metals) in pounds to a cubic inch, and the *linear* expansion (of Metals) between 32° and 212° F: (their *rate* of linear expansion per degree Fahr. is of course $\frac{1}{180}$ of that tabulated), and the Moduli of Tensile, Crushing, and Transverse Strength (f_t, f_c, f_b), and of Tensile Elasticity (E_t) in pounds per square inch, also (for Metals) of Tensile Strength in tons per square inch, *i. e.*, $f_t \div 2240$.

For the definition of these quantities, *see* as follows :—

f_t in Art. 481, Chap. XXII. f_c in Art. 504, Chap. XXIII.
f_b in Art. 461, Chap. XXI. E_t in Art. 513, Chap. XXIV.

The *values of* W, $E_d = \frac{1}{432} \cdot E_t$, f_t, $p_b = \frac{1}{18} f_b$, *for all the common Indian woods* are tabulated at end of Chap. V. Sec. I., *q. v.*

The value of f_c has been determined for *only two* Indian Woods (Sâl and Teak), which have been included in this Table (not being in Chap. V).

Tables VIII. and IX.—Explanation is with the Tables.

* By the writer of Section V.

Nos.	Composition. Quantities.	From whence materials were obtained.	Hours taken in burning.	In what sort of fire.	Color of stone burnt	When mixed and put in water.	Time taken for the setting in water	Quality of the cement under water.	Quality of the cake when exposed to the air.	Result up to 1st April, 1872.	Result up to 30th June, 1872.
18	4 parts of marly clay, B6 1 part of marly clay, B7	Margohi	50	Very strong fire.	Gray.	April 1st	Not set.	Very bad.	Pretty hard.		Crumbled to powder in water after 24 hours.
18i	Ditto	Ditto	70	Very slow fire.	Red.	April 30th	50 m.	Hard.	Rather soft.		Required evidently more burning.
20	8 parts of marly, clay, B7 1 part do, B16	Ditto	50	Very strong fire.	Gray.	May 5th	4 days.	Very hard.	Pretty hard.		Could stand more burning with a strong fire.
24	1 part stone, 48A	Rohtas	110	Very slow fire	Grayish white.	June 10th	2 hours.	Hard.	Hard.		Required more burning, and could stand a stronger fire. This will make a good slow setting cement (I had not enough materials to make another experiment).
30	3 parts of marly clay, B6, 1 part of marly clay, B7, 1½ parts of marly clay, B77,	Margohi	70	Very strong fire.	Yellow.	June 20th	H. 3 M. 15	Pretty hard.	Pretty hard.		Its hardness increases very slowly; it required more burning.
30i	Ditto	Ditto	110	Ditto	Grayish yellow.	June 22nd	10 hours	Hard.	Very hard.		It was burnt very near vitrification, but I should think it required a little more burning.

Note.—It will be observed from this statement that the best sample is No. 2.

It consists of a mixture of $\left\{\begin{array}{l}\text{2 parts of marly clay, B6}\\\text{1 part of ditto, B7}\end{array}\right\}$ from Margohi, which was burnt with a slow fire.

Table III.—Heaviness of Materials not included in following Tables.

Material.	Specific Gravity.	Weight of a cubic foot in pounds.	Remarks.
Air, dry at 32° F., ..	·001225	·080728	
Charcoal, ...	·280 to ·542	17·5 to 33·9	
Clay, ...	1·92	120	
Coal, anthracite, ..	1·602	100	
" bituminous, ..	1·24 to 1·44	77·4 to 89·9	
Coke, ...	1·0 to 1·66	62·43 to 103·6	
Concrete, common, ..	1·9	119	
" cement, ..	2·2	133	
Earth, common, ..	1·52 to 2·0	95 to 125	
" loamy, ..	2·016	126	
" rammed, ..	1·584	99	
" loose, ...	1·52	95	
Felspar, ...	2·6	162·3	
Flint, ...	2·63	164·2	
Glass, crown, average,	2·5	156	
" flint " ..	3·0	187	
" green " ..	2·7	169	
" plate " ..	2·7	169	
Gypsum, ...	2·3	143·6	
Gravel, ...	1·7 to 1·9	109 to 120	
Lime, quick, ...	·8	50	
Marl, ...	1·6 to 1·9	100 to 119	
Mud, ...	1·63	102	
Peat, ...	1·33	83	
Quartz, ...	2·65	165	
Sand (damp), ...	1·9	118	
Sand (dry), ...	1·42	88·6	
Shale, ...	2·6	162	
Shingle, ...	1·4	90	
Tile, ...	1·81 to 1·85	113 to 116	
Trap, ...	2·72	170	
Water, at 39·1° F., ..	1·0	62·425	
" sea, ...	1·026	64·05	

Table IV.—Strength of Portland Cement Mortar.

Material.	Heaviness.	Ratio of cement to sand.	Modulus of Crushing. f_c.			Modulus of Tenacity. f_t.				
			Set 3 Months	Set 6 Months	Set 9 Months	Set 7 Days	Set 1 Month.	Set 3 Months.	Set 6 Months	Set 12 Months.
Portland Cement and Clean Pit Sand	112 lbs. per bushel.	neat	3,795	5,388	5,984	198	302	390	435	478
		1 to 1	2,491	3,478	4,561	68	145	244	284	354
		1 to 2	2,004	2,752	3,647	28	74	201	221	270
		1 to 3	1,436	2,156	2,393	20	41	136	135	189
		1 to 4	1,331	1,797	2,208	10	32	68	122	141
		1 to 5	959	1,540	1,678	..	22	55	97	95

Table I. of 3·6th Powers of Numbers.

Number.	3·6th Power.	Number.	3·6th Power.	Number.	3·6th Power.
1·0	1·0	4·25	182·89	6·8	993·19
1·25	2·2329	4·3	190·76	6·9	1046·8
1·5	4·3045	4·4	207·22	7·0	1102·4
1·75	7·4978	4·5	224·68	7·1	1160·2
2·0	12·125	4·6	243·18	7·2	1220·1
2·1	14·454	4·7	262·75	7·25	1250·9
2·2	17·089	4·75	272·96	7·3	1282·2
2·25	18·529	4·8	283·44	7·4	1346·6
2·3	20·055	4·9	305·28	7·5	1413·3
2·4	23·3755	5·0	328·32	7·6	1482·3
2·5	27·076	5·1	352·58	7·7	1553·7
2·6	31·182	5·2	378·10	7·75	1590·3
2·7	35·720	5·25	391·36	7·8	1627·6
2·75	38·159	5·3	404·94	7·9	1704·0
2·8	40·716	5·4	433·13	8·0	1782·9
2·9	46·199	5·5	462·71	8·25	1991·7
3·0	52·196	5·6	493·72	8·5	2217·7
3·1	58·736	5·7	526·20	8·75	2461·7
3·2	65·848	5·75	543·01	9·0	2724·4
3·25	69·628	5·8	560·20	9·25	3006·8
3·3	73·561	5·9	595·75	9·5	3309·8
3·4	81·908	6·0	632·91	9·75	3634·3
3·5	90·917	6·1	671·72	10·0	3981·07
3·6	100·62	6·2	712·21	10·25	4351·2
3·7	111·05	6·25	733·11	10·5	4745·5
3·75	116·55	6·3	754·44	10·75	5165·0
3·8	122·24	6·4	798·45	11·0	5610·7
3·9	134·23	6·5	844·28	11·25	6083·4
4·0	147·03	6·6	891·99	11·5	6584·3
4·1	160·70	6·7	941·61	11·75	7114·4
4·2	175·27	6·75	967·15	12·0	7674·5

Table II. of 1·7th Powers of Numbers.

Number.	1·7th Power.	Number.	1·7th Power.	Number.	1·7th Power.
1	1·0	9	41·900	17	123·53
2	3·2490	10	50·119	18	136·13
3	6·4730	11	58·934	19	149·24
4	10·556	12	68·329	20	162·84
5	15·426	13	78·289	21	176·92
6	21·031	14	88·801	22	191·48
7	27·332	15	99·851	23	206·51
8	34·297	16	111·43	24	222·00

TABLE III.—HEAVINESS of MATERIALS not included in following Tables.

Material.	Specific Gravity.	Weight of a cubic foot in pounds.	Remarks.
Air, dry at 32° F, ..	·001225	·080728	
Charcoal, ...	·280 to ·542	17·5 to 33·9	
Clay, ...	1·92	120	
Coal, anthracite, ..	1·602	100	
„ bituminous, ..	1·24 to 1·44	77·4 to 89·9	
Coke, ...	1·0 to 1·66	62·43 to 103·6	
Concrete, common, ..	1·9	119	
„ cement, ..	2·2	133	
Earth, common, ..	1·52 to 2·0	95 to 125	
„ loamy, ..	2·016	126	
„ rammed, ..	1·584	99	
„ loose, ...	1·52	95	
Felspar, ...	2·6	162·3	
Flint, ...	2·63	164·2	
Glass, crown, average,	2·5	156	
„ flint „ ..	3·0	187	
„ green „ ..	2·7	169	
„ plate „ ..	2·7	169	
Gypsum, ...	2·3	143·6	
Gravel, ...	1·7 to 1·9	109 to 120	
Lime, quick, ...	·8	50	
Marl, ...	1·6 to 1·9	100 to 119	
Mud, ...	1·63	102	
Peat, ...	1·33	83	
Quartz, ...	2·65	165	
Sand (damp), ...	1·9	118	
Sand (dry), ...	1·42	88·6	
Shale, ...	2·6	162	
Shingle, ...	1·4	90	
Tile, ...	1·81 to 1·85	113 to 116	
Trap, ...	2·72	170	
Water, at 39·1 F, ..	1·0	62·425	
„ sea, ...	1·026	64·05	

TABLE IV.—STRENGTH OF PORTLAND CEMENT MORTAR.

Material.	Heaviness.	Ratio of cement to sand.	Modulus of Crushing. f_c.			Modulus of Tenacity. f_t.				
			Set 3 Months.	Set 6 Months	Set 9 Months	Set 7 Days.	Set 1 Month.	Set 3 Months.	Set 6 Months.	Set 12 Months.
Portland Cement and Clean Pit Sand	112 lbs. per bushel.	neat	3,795	5,388	5,984	198	302	390	435	478
		1 to 1	2,491	3,478	4,561	68	145	244	294	354
		1 to 2	2,004	2,752	3,647	28	74	201	221	270
		1 to 3	1,436	2,156	2,393	20	41	136	155	189
		1 to 4	1,331	1,797	2,208	10	32	68	122	141
		1 to 5	959	1,540	1,678	..	22	55	97	95

Table I. of 3·6th Powers of Numbers.

Number.	3·6th Power.	Number.	3·6th Power.	Number.	3·6th Power.
1·0	1·0	4·25	182·89	6·8	993·19
1·25	2·2329	4·3	190·76	6·9	1046·8
1·5	4·3045	4·4	207·22	7·0	1102·4
1·75	7·4978	4·5	224·68	7·1	1160·2
2·0	12·125	4·6	243·18	7·2	1220·1
2·1	14·454	4·7	262·76	7·25	1250·9
2·2	17·089	4·75	272·96	7·3	1282·2
2·25	18·529	4·8	283·44	7·4	1346·6
2·3	20·055	4·9	305·28	7·5	1413·3
2·4	23·3755	5·0	328·32	7·6	1482·3
2·5	27·076	5·1	352·58	7·7	1553·7
2·6	31·182	5·2	378·10	7·75	1590·3
2·7	35·720	5·25	391·36	7·8	1627·6
2·75	38·159	5·3	404·91	7·9	1704·0
2·8	40·716	5·4	433·13	8·0	1782·9
2·9	46·190	5·5	462·71	8·25	1991·7
3·0	52·196	5·6	493·72	8·5	2217·7
3·1	58·736	5·7	526·20	8·75	2461·7
3·2	65·848	5·75	543·01	9·0	2724·4
3·25	69·628	5·8	560·20	9·25	3006·85
3·3	73·561	5·9	595·75	9·5	3309·8
3·4	81·908	6·0	632·91	9·75	3634·3
3·5	90·917	6·1	671·72	10·0	3981·07
3·6	100·62	6·2	712·22	10·25	4351·2
3·7	111·05	6·25	733·11	10·5	4745·5
3·75	116·55	6·3	754·44	10·75	5165·0
3·8	122·24	6·4	798·45	11·0	5610·7
3·9	134·23	6·5	844·28	11·25	6083·4
4·0	147·03	6·6	891·99	11·5	6584·3
4·1	160·70	6·7	941·61	11·75	7114·4
4·2	175·26	6·75	967·15	12·0	7674·5

Table II. of 1·7th Powers of Numbers.

Number.	1·7th Power.	Number.	1·7th Power.	Number.	1·7th Power.
1	1·0	9	41·900	17	123·53
2	3·2490	10	50·119	18	136·13
3	6·4730	11	58·931	19	149·24
4	10·556	12	68·329	20	162·84
5	15·426	13	78·289	21	176·92
6	21·031	14	88·801	22	191·48
7	27·332	15	99·851	23	206·51
8	34·297	16	111·43	24	222·00

TABLE III.—HEAVINESS of MATERIALS not included in following Tables.

Material.	Specific Gravity.	Weight of a cubic foot in pounds.	Remarks.
Air, dry at 32° F., ..	·001225	·080728	
Charcoal, ...	·280 to ·542	17·5 to 33·9	
Clay, ...	1·92	120	
Coal, anthracite, ..	1·602	100	
„ bituminous, ..	1·24 to 1·44	77·4 to 89·9	
Coke, ...	1·0 to 1·66	62·43 to 103·6	
Concrete, common, ..	1·9	119	
„ cement, ..	2·2	133	
Earth, common, ..	1·52 to 2·0	95 to 125	
„ loamy, ..	2·016	126	
„ rammed, ..	1·584	99	
„ loose, ...	1·52	95	
Felspar, ...	2·6	162·3	
Flint, ...	2·63	164·2	
Glass, crown, average,	2·5	156	
„ flint „ ..	3·0	187	
„ green „ ..	2·7	169	
„ plate „ ..	2·7	169	
Gypsum, ...	2·3	143·6	
Gravel, ...	1·7 to 1·9	109 to 120	
Lime, quick, ...	·8	50	
Marl, ...	1·6 to 1·9	100 to 119	
Mud, ...	1·63	102	
Peat, ...	1·33	83	
Quartz, ...	2·65	165	
Sand (damp), ...	1·9	118	
Sand (dry), ...	1·42	88·6	
Shale, ...	2·6	162	
Shingle, ...	1·4	90	
Tile, ...	1·81 to 1·85	113 to 116	
Trap, ...	2·72	170	
Water, at 39·1 F., ..	1·0	62·425	
„ sea, ...	1·026	64·05	

TABLE IV.—STRENGTH OF PORTLAND CEMENT MORTAR.

Material.	Heaviness.	Ratio of cement to sand.	Modulus of Crushing. f_c. Set 3 Months.	Set 6 Months.	Set 9 Months.	Modulus of Tenacity. f_t. Set 7 Days.	Set 1 Month.	Set 3 Months.	Set 6 Months.	Set 12 Months.
Portland Cement and Clean Pit Sand	112 lbs. per bushel	neat	3,793	[illegible]	[illegible]	198	[illegible]	[illegible]	[illegible]	[illegible]
		1 to 1	2,491	3,478	[illegible]	68	165	[illegible]	[illegible]	[illegible]
		1 to 2	[illegible]	2,752	3,647	[illegible]	74	[illegible]	221	[illegible]
		1 to 3	1,436	2,156	[illegible]	[illegible]	41	[illegible]	[illegible]	[illegible]
		1 to 4	1,331	1,797	[illegible]	10	[illegible]	[illegible]	[illegible]	[illegible]
		1 to 5	959	1,540	[illegible]	..	[illegible]	[illegible]	97	[illegible]

Table V.—Weight and Strength of Stone, Earth, &c.

Class.	Material.	Specific Gravity.	Weight of a cubic foot in pounds. W	Moduli of Strength. Tensile. f_t	Crushing. f_c	Cross-breaking. f_b	Modulus of Direct Tensile Elasticity. E_t	Remarks.
Rocks and Stones.	Basalt (whin-stone),	2·478 to 3	155 to 187	......	8,000 / 17,000	......	......	
	Chalk, ...	1·87 to 2·78	117 to 174	......	330 / 500	......	......	
	Granite, ...	2·63 to 2·76	164 to 172	......	5,500 / 11,000	......	......	
	Lime-stone (marble),	2·7 to 2·8	169 to 175	550 to 700	5500	......	......	
	" (granular)	2·6	163	......	4000 / 4500	......	......	
	" (compact),	2·86	178	......	7,000 / 8,500	......	......	
	Sand-stone (various),	2·08 to 2·52	130 to 157	......	2,200 / 5,500	1,100 / 2,360	......	
	" (average),	2·3	144	......	3,300 / 4,400	......	......	
	Slate, ...	2·8 to 2·9	175 to 181	9,600 / 12,800	11,000 / 20,000	5,000	13,000,000 / 16,000,000	
	Syenite, ...	2·62	164	....	11,800	......	......	

ARTIFICIAL SUBSTANCES. Béton {of mortar and flints},	......	......	......	420	......	......
Brick, weak, ...	2 to 2·08	130	......	550 to 800	......	......
" good, ...	2·1 to 2·17	130 to 135	280 to 300	800 to 1100	......	......
" fire, ...	2·4	150	......	1700	......	......
Brickwork in mortar,	1·6 to 1·7	100 to 112	*See* Mortar.			
" cement,	1·6 to 1·7	100 to 112	270 to 300	1000	......	......
Cement, Portland, ..	1·3	81	*See* Table IV.	*See* Table IV.		
" Roman, ..	1·6	100	38 to 143	......	......	......
Glass, ...	2·45 to 3·08	......	2100 3500 9400	27,000 31,000	......	8,000,000
Mortar, common, ..	1·4 to 1·6	88 to 100	20 to 50	......	......	......
" good, ..	1·5 to 1·9	91 to 118	80 to 135	......	......	......
Masonry, ...	1·85 to 2·3	116 to 144	*See* Mortar.			
" rubble, ..	......	......	*See* Mortar.	$\frac{4}{10}$ of Ashlar.	......	......
Plaster of Paris, ..	1·29	80	70	......	......	......

TABLE VII.—PROPERTIES OF METALS.

Material.	Specific Gravity.	Weight. Of a cubic inch in pounds.	Weight. Of a cubic foot in pounds. W	Moduli of Strength. Tensile. f_t	Moduli of Strength. Crushing. f_c	Modulus of Direct Tensile Elasticity. E_t	Value of $\frac{f_t}{2240}$	Expansion from 32° F. to 212° F.	Remarks.
Brass, cast, ...	7·8 to 8·4	·28 to ·3	487 to 524	18,000	10,300	9,170,000	8·02	·0019	
" wire, ...	8·54	·31	533	49,000 91,000	......	14,230,000	21·87 40·77	·0019	
Copper, cast, ...	8·6	·31	537	19,000	11,700	......	8·51	·0017	
" sheet, ...	8·8	·32	549	30,000	......	......	13·4	......	
" bolts, ...	8·9	·33	556	36,000 48,000	......	......	16·07 21·4	....	
" wire {annealed un-annealed}	9·0	·33	562	32,100 77,500	....	 17,000,000	14·35 34·6	....	
Gun-metal {8 copper to 1 tin,}	8·4	·3	524	36,000	......	9,900,000	16·07	......	
Iron-cast (various), ..	6·95 to 7·3	·25 to ·26	434 to 456	13,400 29,000	82,000 145,000	14,000,000 22,300,000	6·0 12·9	....	
" " (average), ..	7·11	·26	444	16,500	112,000	17,000,000	7·3	·0011	
plate, ...	7·6 to 7·8	·27 to ·28	474 to 487	51,000	36,000	24,000,000?	22·7	·0012	
joints, double riveted,	......	......	......	35,700	......	......	....	......	

Iron, Wrought, joints, single rivetted,	......	......	......	28,000	......	......	......	......
Iron, Wrought, bar and bolt, ..	7·6 to 7·8	·27 to ·28	474 to 487	{ 60,000 / 70,000 }	{ 30,000 / 40,000 }	29,000,000	{ 26·78 / 31·2 }	·0012
Iron, Wrought, hoop, best-best, ..	......	......	......	64,000	......	......	28·6	......
Iron, Wrought, wire, ...	......	......	......	{ 70,000 / 100,000 }	......	25,300,000	{ 31·2 / 44·6 }	·0014
Iron, Wrought, wire-rope, ...	......	......	......	90,000	......	15,000,000	40·2	......
Lead, cast, ...	11·35	·41	709	1,824	7,000	......	·81	·0028
„ sheet, ...	11·4	·41	712	{ 1,900 / 3,300 }	......	720,000	{ ·86 / 1·47 }	......
Steel, bars, ...	7·78	·28	485	{ 100,000 / 130,000 }	......	{ 29,000,000 / 42,000,000 }	{ 44·6 / 58·0 }	·0011
„ plates (average), ..	7·8 to 7·9	·28 to ·29	487 to 493	80,000	......	......	35·7	·0011
„ puddled, ...	7·78	·28	485	{ 70,000 / 110,000 }	......	{ 24,800,000 / 20,500,000 }	{ 31·2 / 51·8 }	......
Tin, cast, ...	7·3 to 7·5	·26 to ·27	456 to 468	4,600	15,000	......	2·12	·0021
Zinc, ...	6·9 to 7·2	·24 to ·26	424 to 449	{ 7,000 / 8,000 }	......	......	{ 3·12 / 3·57 }	·0029

TABLE VIII.—RESISTANCE to SHEARING.

Class.	Material.	Modulus of Shearing Strength. f_s.	Modulus of Transverse (Shearing) Elasticity. E_s.	Remarks.
METALS.	Brass wire drawn, ...	......	5,330,000	For definition of E_s, *see* Art. 646 of this Treatise. The constants for shearing have been determined for very few materials.
	Copper,...	......	6,200,000	
	Iron, cast, ...	27,700	2,850,000	
	Iron, wrought, ...	50,000	{ 8,500,000 9,500,000	
TIMBER.	Ash, ...	1,400	76,000	
	Elm, ...	1,400	76,000	
	Fir, larch, ...	970 to 1,700	......	
	„ red pine, ...	500 to 800	{ 62,000 116,000	
	„ spruce, ...	600	......	
	Oak (Normandy), ...	2,300	82,000	

TABLE IX.—RESILIENCE OF IRON.

Material.	Modulus of Tensile Resilience. $f_t^2 \div E_t$.	Reciprocal of Modulus. $E_t \div f_t^2$.	Remarks.
Cast-iron, weak, ...	12·823	·0780	*See* Arts. 477, 552, 553 of this Treatise.
„ average, ...	16·02	·0624	
„ strong,...	36·72	·0272	
Bar-iron, good average, ...	124·11	·0081	
Plate-iron, „	101·13 ?	·0096 ?	
Iron-wire, „	320·13	·0031	
Steel, soft, ...	279·27	·0036	
„ hard, ...	414·0	·0024	

APPENDIX III.

TECHNICAL VOCABULARY.

Orthography.

The spelling of the Hindustani words is the same as now generally adopted* in technical works (as in Dr. D. Forbes's Hindustani Books), except that the diacritical marks of consonants have in general been omitted. The spelling indicates at once the *pronunciation* and also the *correct spelling* in the Oriental characters (except minor differences in consonants which have been considered unnecessary to the Engineer).

Pronunciation of Vowels.

a	as the first vowel in *papa, mamma.*
á	as the last vowel in *papa, mamma.*
e	as the vowel sound in *late, rate.*
i	as in *din, pin.*
í	as the vowel sound in deed, meet.
o	as in *hole, pole.*
u,	as in French or German. as the vowel sound in good, foot.
ú	as the vowel sound in *boot, root.*
au	as the vowel sound in *how, now.*
ai	as the vowel sound in *bite, kite.*

Pronunciation of Consonants.

Consonants to be pronounced *in general* as in English:—except as follows:—

ph, th, must invariably be separately pronounced, *i. e.*, as in *uphill, pothook*, (not as in *philosophy, thing*).

kh, gh, as in English.

kh, as the Scotch or German *ch*, as in *loch.*

gh, nearly as in *McLaughlin.*

* Also known as the Hunterian System.

Building.—(*Continued.*)

Pansál karná	to level	Shahtír, latthá	beam.
Pár	scaffolding.	Sírhí	ladder.
Patthar	stone.	Sur*kh*í	pounded bricks.
Pílpáya	pillar.	Sút, sútlí	thread tracing line.
Raddá	course, layer.	Tánkí	stonemason's chisel.
Sáwal, sákúl	plummet.	Tikantí	mason's level.

Bridge Building.

Atráf	haunches.	Kinára	bank edge
Band	bonding.	Naddí	small river.
Daryá	large river.	Páya	pier.
Dát	key-stone.	Pul	bridge.
Fasíl, mader	parapet.	Rás mihráb	crown of the arch.
Jor	joint.	Sarak	road
*Kh*am	splay.	Talí	bottom.

Carpentry.

A'rá	large saw.	Kiwára	door.
A'rí	hand saw.	Kú'e kí bunyád	well foundation.
Auzár, hathiyár	tools	Kulhárá	large felling axe.
Barmá	auger, brace, & bit.	Kulhárí	small felling axe.
Basúlá	adze.	Le'í	paste.
Billí	doorbolt, bar.	Mez	table.
Birinjí	tack.	Mín	bradawl.
Buráda	sawdust.	Muchák	pile driver.
Chábí	key.	Nímchak	curb under well-ring.
Charkhí	windlass.		
Chaukhat	door frame.	Parkár	pair of compasses.
Chitkiní	sliding bolt.	Pechkash	screw driver.
Chúl	tenon.	Pípá	barrel.
Dilhá	panel.	Preg, kíl	nail.
Gaz-mistar	straight edge.	Randa	plane.
Ghirní	block or pulley.	Retí	file.
Gol-árí	circular saw.	Rukhání	chisel.
Gond	gum.	Sandúk	chest, box.
Jorí	pair (of doors).	Shikanja	press, cramp.
Kabza	hinge.	Sresh	glue.
Khirkí	window.	Tálá	lock.

Thatching.

Bán	múnj string.	Pulá	bundle of thatching grass.
Báns	bamboo.		
Barerí	ridge pole.	San	kind of flax.
Bínd	reed, fascine.	Saní	same, long & coarse.
Boriyá, chatá'í	small mat.	Sarkanda	name of a reed.
Jhámp	mat screen.	Senthá	single stem of ditto.
Kans	coarse thatching grass.	Sirkhí	the upper part of sarkanda.
Múnj	grass rope.	Sút	thread, string.
Parda	shutter.	Sút kí rassí	cotton rope.
Phúns	thatching grass.	Sútlí	twine.

Metals, &c.

Ashtdhát	bell metal.	Lohá gol	rod iron.
Chándí	silver.	Lohá kundlí	hoop iron.
Dhát, fliz	metal.	Lohá sarrí	pig iron.
Ispát, fúlád	steel.	Lohá tár	iron wire.
Jast	zinc.	Párá, símáb	quicksilver.
Lohá	iron.	Pítal	brass.
Lohá chádrí	sheet iron.	Rángá, kalá'í	tin.
Lohá chaptá	flat iron.	Sísá	lead.
Lohá chaukor	bar iron.	Támrá	copper.

Painter's Work.

A'ína	pane of glass.	Pílí mattí	yellow ochre.
Alsí ká tel	linseed oil.	Sankhiyá	arsenic.
Dabbá	leathern oil vessel.	Sendúr	red lead.
Ganda-biroza, tarpantel	turpentine.	Shísha, kánch	glass, phial.
Gerú	red ochre.	Síl	stone for grinding color on.
Hartál	orpiment.	Sísá	lead.
Hál	sugar of lead.	Sufedá	white lead.
Káfúr	camphor.	Tarpín ká tel	oil of turpentine.
Kájal	lamp black.	Tel	oil.
Khariyá mattí	chalk, whiting.	Tel, alsí ká	linseed oil.
Lílá tútiyá	blue vitriol.	Tel, náriyal ká	cocoanut oil.
Multání mattí	yellow ochre.	Tel, sarson ká	mustard oil.
Nil	indigo.	Tel, til ká	sweet oil.

Blacksmith's Work.

Angethí	fireplace.	Kábila	screw bolt.
Bank	vice.	Kainchí	scissors.
Chamrá	leather.	Koelá	charcoal.
Chhenî	small wedge, chisel.	Mez kí bank	large vice.
Chimtá	pincers.	Pachhar	wedge.
Damkash, dhaunkní	bellows.	Phúlí, pattí	washer.
Dhálá hú'á	cast.	Rál	rosin.
Dhálná	to cast.	Ráng	solder.
Dhiblí	nut.	Sambá	punch.
Dhiblí-kash	nut-key.	Sandásí, chimtá	tongs.
Ghan	sledge hammer.	Sohan	file, rasp.
Hathaurá	small ditto.	Tá'o	red hot.
Hath kí bank	hand vice.	Tá'ó dena	to heat.
Jelí	rake.	Tárkash	wire-drawer.

Surveying.

Dasfutá	ten-foot rod.	Matám	bench-mark.
Dúrbín	telescope.	Naksha	map.
Farzí khatt	datum line.	Naksha banáná	to plot.
Fítá kí jarríb	tape.	Náp	measure.
Gaz	staff.	Paimá'ish	survey.
Hamwárí	levelling.	Paimá'ish karna	to survey.
Jarríb	chain.	Pakká matám	permanent bench-mark.
Jhandí	flag.	Sú'á	arrow.
Kampás	surveying instrument.	Tílon ká dhál	contouring.
Khuntí	peg.	Típá'í	tripod stand.

INDEX TO VOL. I.

The Numbers refer to the Paragraphs.

A.

B.

C.

D.

F.

G.

H.

I.

N.

O.

P.

Q.

R.

N.

O.

P.

T.

S.

T.

U.